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INFLUENCE OF LAND USE CHANGES IN A QUARTER CENTURY ON SOIL EROSION AND SEDIMENT DELIVERY OF THE LAM PHACHI WATERSHED, WESTERN THAILAND

Hideji Maita[1], Masanobu Kimura[2], Kosit Lorsirirat[3],
Tomomi Marutani[4], Mutsuki Higo[5], Shigeo Ogawa[6]

ABSTRACT

We revealed two stages of land use changes in the Lam Phachi watershed. The first stage is the forest conversion to cultivated lands that was practiced in the entire basin two or three decades ago. The second stage is the dynamic cultivation changes that have occurred on the converted lands related to a shift to a more profitable cash crop culture since the 1990s. Crop fields have significantly lower final infiltration rates (5 to 39 mm/hr) than forestlands (44 to 160 mm/hr) and are therefore more susceptible to erosion than forestlands. In particular, severe soil erosion problems have occurred in some pineapple fields on sloping areas, demonstrated by erosion rates of survey plots of 69 and 163 t/ha/yr. However, the analysis of suspended sediment monitoring data suggests that much of the sediment produced by soil erosion in the second stage may not reach streams. Irrigation ponds that support the recent cash crop culture may trap the sediment. Conversely, the sediment produced by deforestation in the first stage could rapidly spread to streams in the initial decade following cropland establishment. Such past sediment disturbance in the watershed may have affected recent channel processes in such a way that the primary sediment entering streams, coupled with the secondary sediment produced by bank erosion etc., is transported downstream.

Keywords: soil erosion, infiltration capacity, forest, pineapple field, sediment delivery

INTRODUCTION

The Lam Phachi watershed, located in western Thailand near the Myanmar border, was deemed as a frontier for a long time due to disadvantageous traits caused partly by specific topographical conditions. Approximately 30 years ago, early settlers from a neighboring area began to clear forests in downstream areas of the watershed to practice rain-fed farming, and succeeding settlers have expanded the cultivated land into upstream forest areas. For the last decade, dynamic cultivation changes have occurred on the converted land from forests, causing severe soil erosion problems in some sloping areas upstream.

1 Institute of Agricultural and Forest Engineering, University of Tsukuba, Tsukuba Ibaraki 305-8572 Japan (Tel.: +81-29-853-4652; Fax: +81-29-855-2203; email: htyhi@sakura.cc.tsukuba.ac.jp)
2 Faculty of Agriculture, Gifu University, Yanagido Gifu 501-11 Japan
3 Hydrology Division, Royal Irrigation Department, Dusit Bangkok 10300 Thailand
4 Faculty of Agriculture, Shinshu University, Kami-ina Nagano 399-4598 Japan
5 Faculty of Regional studies, Gifu University, Yanagido Gifu 501-11 Japan
6 National Institute for Rural Engineering, Tsukuba Ibaraki 305-8609 Japan

We attempted to clarify the influence of the forest conversion to cultivated lands and recent dynamic cultivation changes on soil erosion and sediment delivery by conducting infiltration capacity tests; soil survey and soil erosion measurements; and analyzing satellite imagery data, aerial photographs, and suspended sediment concentration data.

STUDY AREA AND METHODS

The Lam Phachi River drains a 2620 km^2 basin which is located in the western part of Thailand near the Myanmar border. It runs north and joins the Tha Khoei River (basin area: 637 km^2), the largest tributary at Ban Tha Khoei, the centre of the watershed. The relief of the watershed declines from 1020 m in the headwaters to 30 m at the confluence with the Khwae Noi River (Fig. 1). The watershed receives an average of 1130 mm rainfall annually, 90 percent falling during the rainy season between May and November, and 10 percent falling during the dry season between December and April (Maita *et al*., 1998). Igneous rocks of the Mesozoic Period and sedimentary rocks of the Paleozoic Period underlie the headwaters and the ridge along the Myanmar border of the watershed. Sedimentary rocks of the Quaternary Period underlie the lowland of the watershed. The analysis, using remotely sensed data in 1994 and 1995, indicated that the forestland ratio to the entire basin was 56 percent, and the agricultural land ratio was 37 percent (Maita *et al*., 1999).

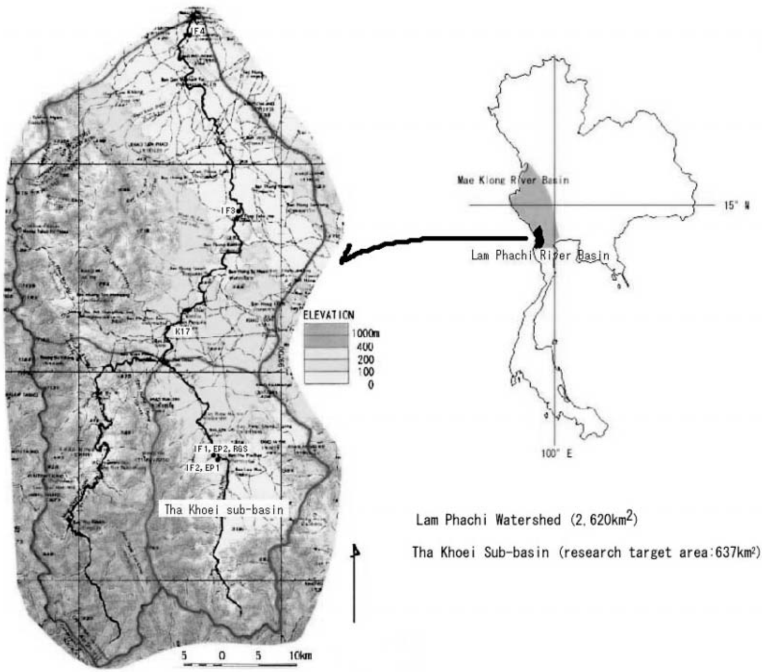

Fig. 1 Map showing the Lam Phachi watershed and the Tha Khoei sub-basin.
IF1-IF4: Infiltration capacity test sites. EP1-EP2: Soil erosion measurement plots.
RGS: Rain gage station. K17: Hydrological monitoring site of RID.

We analyzed changes in the conversion of forests to cultivated lands in the entire watershed, and recent dynamic cultivation changes in the Tha Khoei sub-basin, using satellite image data (Landsat/MSS (1974/01/07), Landsat/TM (1989/01/11), Landsat/TM (1993/01/30), Landsat/ETM+ (1999/12/25), Landsat/ETM+ (2000/11/30)) and ground survey data, and also analyzed the deformation of the stream channel form from the junction with the Tha Khoei River to the river mouth (about 70 km distance) using aerial photographs taken in 1974 and 1998 by the Royal Survey Department, and field survey data (Fig. 2).
We surveyed the rill and gully erosion in pineapple fields in a sloping area of the Tha Khoei sub-basin because we found sporadic soil erosion in the pineapple fields on the sloping area of this sub-basin. To compare the infiltration rate of forestlands with pineapple and other crop fields, we conducted an infiltration capacity test using a cylinder type infiltrometer at four sites, IF1, IF2, IF3 and IF4 selected from the upstream to the downstream along the river (Figs 1 and 2). In addition, we analyzed historical changes of suspended sediment concentration using monitoring data at the K17 site of the Royal Irrigation Department (about 5 km downstream form the junction with the Tha Khoei River; basin area: 1355 km^2).

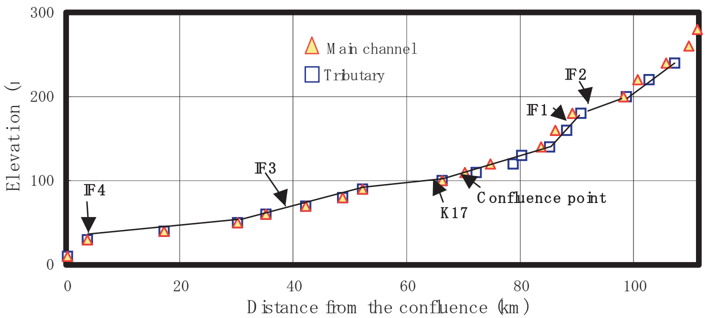

Fig. 2 Longitudinal profile of the Lam Phachi River.

RESULTS

Land Use Changes From Satellite Image Analysis and Channel Form Deformation From Aerial Photograph Interpretation

Figure 3 illustrates the conversion of forests to cultivated lands in the Lam Phachi watershed in the last quarter century as analyzed by satellite image data. Green represents forests, and red represents cultivated and bare lands, including fallow areas.
Forests covered the entire watershed at the beginning of the 1970s; after that, they rapidly decreased to about half in 1990 due to the expansion of cultivated lands. Thus, the conversion of forests to cultivated lands has been the most widespread land use change in the Lam Phachi watershed in the 1970s and 1980s. However, between 1990 and 2000, the forest cover ratio in the Lam Phachi watershed has been relatively stable, and the forest cover ratio in the Tha Khoei sub-basin has also been relatively stable at some 60 percent (Fig. 3). Dynamic cultivation changes have occurred on the converted land related to a shift to a more profitable cash crop culture since the 1990s. Main cash crops in the Tha Khoei sub-basin are pineapple, sugarcane, cassava and vegetables. Of these, the pineapple cultivation leads to high

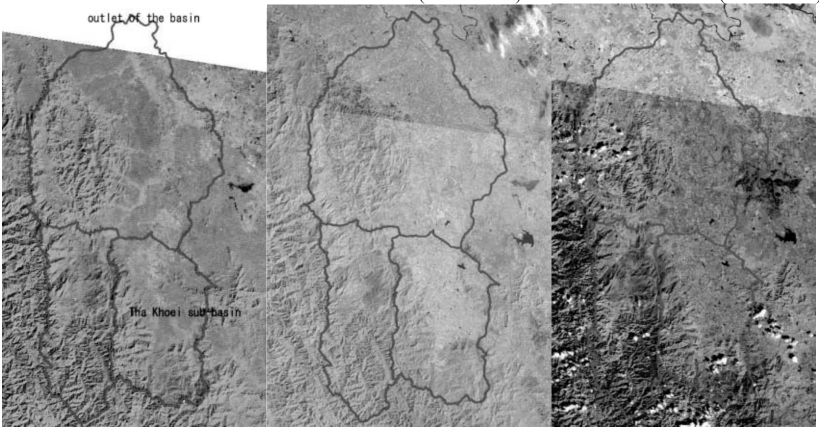

Fig. 3 Conversion of forests to cultivated lands in the Lam Phachi watershed in the last quarter century.

susceptibility to soil erosion because the fields are exposed to rainwater during the field clearing, tillage and succeeding early growth stages every three years to plant saplings. Furthermore, pineapple cultivation has been expanding to the sloping areas of the mountain foot. Therefore, we focused on the pineapple cultivation to identify soil erosion problems caused by the dynamic cultivation changes since the 1990s. Table 1 summarizes the pineapple field area in 1993 and 2000, and Table 2 shows area changes for each crop type from 1993 to 2000 in the Tha Khoei sub-basin. Figure 4 also depicts area changes classified by slope angles of each crop field from 1993 to 2000.

The pineapple cultivation area increased by approximately 20 percent during the last decade (Table 1). However, during this period, the cultivation area that changed from pineapples to other crops including fallow areas reached approximately 70 percent, leaving the pineapple cultivation area at 30 percent (Table 2). Figure 4 indicates that the pineapple cultivation developed even on quite steep slopes (9 to 12 degrees or more).

Table 1 Area change of pineapple field.

Year	Pineapple field area (ha)
1993	5276
2000	6289

Table 2 Area changes of crop types.

Crop type changes from 1993 to 2000	Changed area (ha)
Other crops and fallow ⇒ Pineapple	4752
Pineapple ⇒ Other crops and fallow	3702
Pineapple ⇒ Pineapple	1574

Figure 5 illustrates stream channel changes from 1974 to 1998 in the lowland areas between 38 and 40 km upstream from the river mouth (near the IF3 point in Figs. 1 and 2). In this reach, the river had widened in 1998 to approximately three times the width in 1974. According to Kimura *et al.* (2002), this reach was categorized as a lateral migration with massive sedimentation. It should be noted that many forests existed along the entire river in 1974, although by 1998 they had been destroyed to develop cultivated lands.

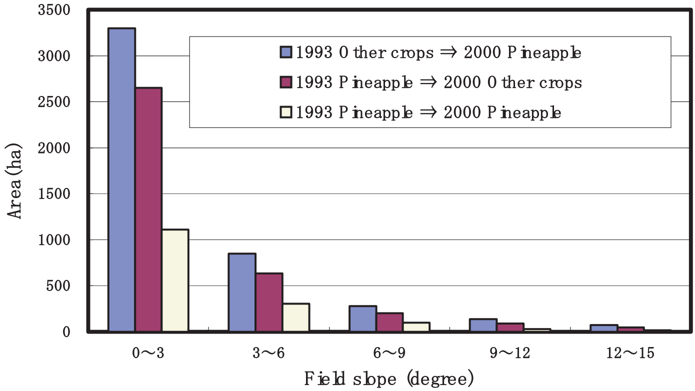

Fig. 4 Changes of area classified by slope angles of each crop field from 1993 to 2000 in the Tha Khoei sub-basin.

1993 Other crops⇒2000 Pineapple: The conversion of other crop fields in 1993 to pineapple fields in 2000
1993 Pineapple⇒2000 Other crops: The conversion of pineapple fields in 1993 to other crop fields in 2000
1993 Pineapple⇒2000 Pineapple: No change

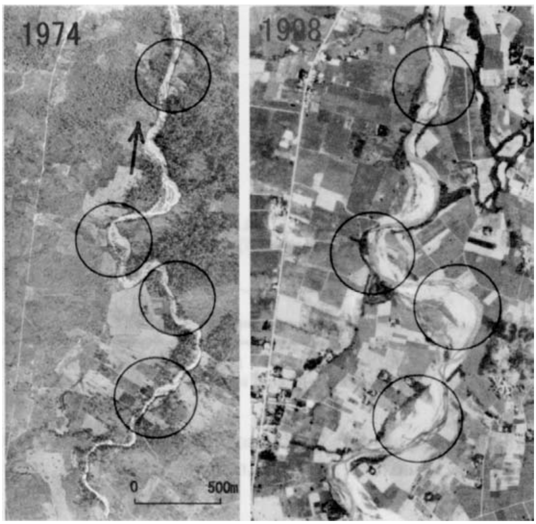

Fig. 5 Changes of channel form from 1974 to 1998 in the lowland areas between 38 and 40 km upstream from the river mouth

Infiltration Capacity of Forest Soil and Crop Field Soil

We selected four sites to compare the infiltration capacity of forest soil with that of crop field soil (Figs. 1 and 2). Each site, with the exception of the IF4 site, has two adjacent plots to test the infiltration rates of forest and crop soils. Judging from the species composition, these forests are secondary forests. Comparing the final infiltration rate of forest soil with that of pineapple field soil at the IF1site, located at the foot of hilly land, the rate of forest soil (160 mm/hr) was remarkably higher than that of the pineapple field soil (28 mm/hr) (Fig. 6). However, both soils have similar characteristics, except that the forest soil has a 5 cm thick surface layer of humus (Figs. 10 and 11).

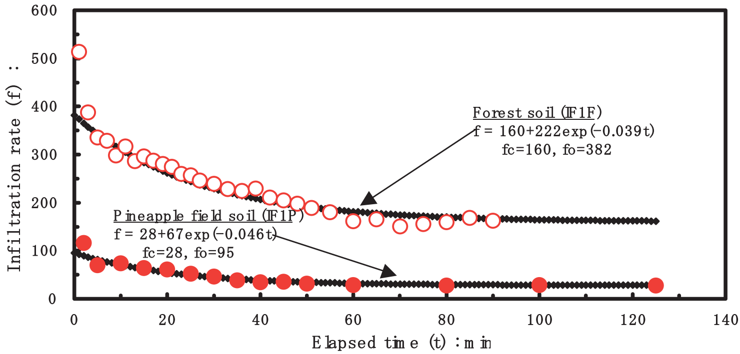

Fig. 6 Infiltration capacity curves of the forest soil and the pineapple field soil at the IF1 site. f: Horton equation. fc: final rate. fo: initial rate.

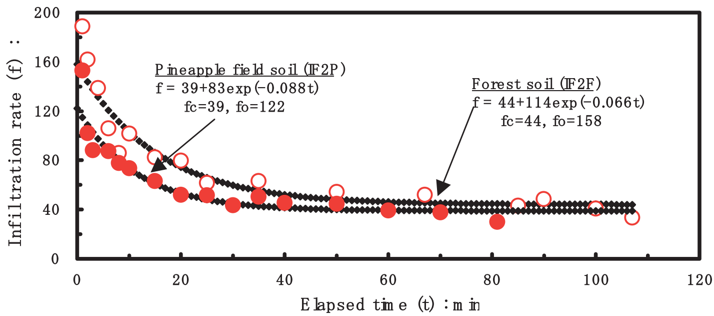

Fig. 7 Infiltration capacity curves of the forest soil and the pineapple field soil at the IF2 site. f: Horton equation. fc: final rate. fo: initial rate.

At the IF2 site, located at the top of hilly land, the forest soil infiltration rate (44 mm/hr) is similar to the pineapple field soil (39 mm/ hr) as compared to the IF1 site (Fig. 7). Both forest soil and pineapple field soil are not so deep (30 to 40 cm in depth), and both soils are similar in their profile, texture and hardness.

At the IF3 site, located on the floodplain near the stream, the infiltration rate of forest soil (130 mm/hr) is considerably higher than that of the sugarcane field soil (20 mm/hr) (Fig. 8). Judging from the soil texture and hardness, the forest plot for the infiltration test may have been selected on a sand dune of the former riverbed. Soil characteristics of the forest plot are considerably different from those of the sugarcane plot, although the soil of both plots is quite deep (more than 80 cm in depth).

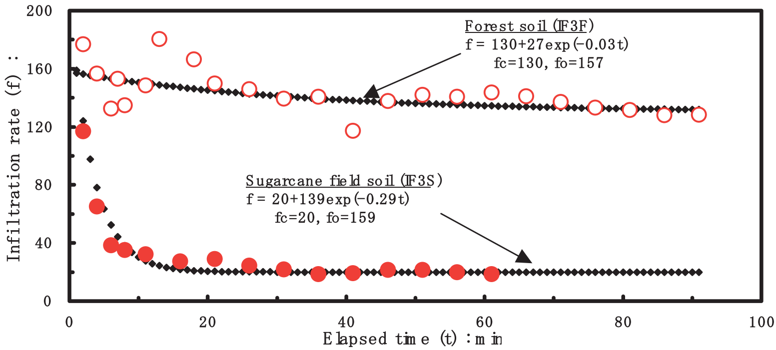

Fig. 8 Infiltration capacity curves of the forest soil and the sugarcane field soil at the IF3 site. f: Horton equation. fc: final rate. fo: initial rate.

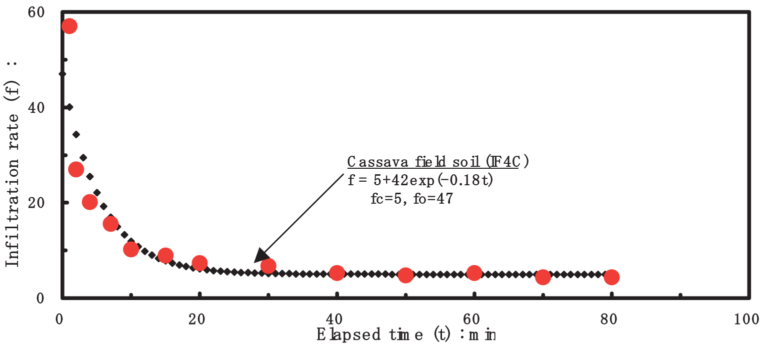

Fig. 9 Infiltration capacity curve of the cassava field soil at the IF4 site. f: Horton equation. fc: final rate. fo: initial rate.

The IF4 site was selected on the floodplain just above the confluence of the main river (Khwae Noi River) for the infiltration test for the cassava field. The cassava field soil infiltration rate (5 mm/hr) is quite low (Fig. 9). The profile, texture and hardness of soil suggest that indurated layers (called hardpans) may be formed in the layer below 20 cm depth from the surface. The hardpans cause a low final infiltration rate. Such a low rate, coupled with the accordance of the direction in both floodplain's slope and cassava rows, causes severe bank erosion, as shown in Fig. 12.

Soil profile of secondary forest at IF1F
Survey date: July 27, 2001
Slope angle: 11.5 degree

Soil hardness

Soil layer		Soil hardness
A0	Humus	
A1	Organic matter	7 kg/cm^2
A2	Gravel<30%	8.5 kg/cm^2
B	Gravel<90%	8.5 kg/cm^2

Soil texture

Sample No	Sand %	Silt %	Clay %	Texture
A0(0-3)	70.72	20.68	8.60	Sandy Loam
A1(3-10)	72.34	10.17	17.49	Sandy Loam
A2(10-25)	72.67	17.58	9.75	Sandy Loam
B(25-45)	72.78	17.76	9.46	Sandy Loam
B(45-65)	77.29	13.46	9.25	Sandy Loam
B(65-)	77.05	13.95	9.00	Sandy Loam

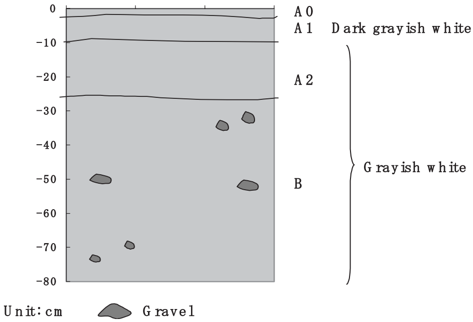

Fig. 10 Soil characteristics of the secondary forest at the IF1 site.

Soil profile of pineapple field (first year growth) at IF1P
Survey date: July 25, 2001

Soil hardness

Soil layer		Soil hardness
A	Gravel<5%	2.9 kg/cm^2
B1	Gravel<10%	9.0 kg/cm^2
B2	Gravel=80%	3.3 kg/cm^2

Soil texture

Sample No.	Sand %	Silt %	Clay %	Texture
A(0-25)	75.60	15.59	8.81	Sandy Loam
B1(25-40)	73.37	17.08	9.55	Sandy Loam
B2(40-60)	73.24	13.89	12.87	Sandy Loam
B2(60-80)	78.18	10.27	11.55	Sandy Loam

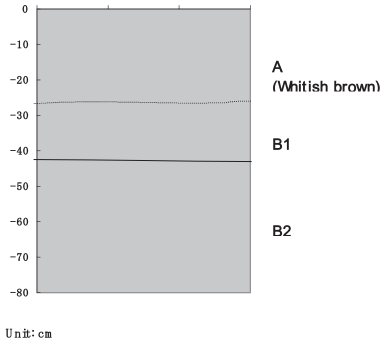

Fig. 11 Soil characteristics of pineapple field at the IF1 site.

Fig. 12 Severe bank erosion caused by the accordance of the direction in both floodplain's slope and cassava rows coupled with quite low infiltration capacity due to hardpans.

Soil Erosion Rates of Pineapple Fields

Figure 13 depicts rill erosion at the EP1 plot, a one-year growth pineapple field with 11 percent maximum slope, and Fig. 14 presents rill and gully erosion at the EP2 plot, a three-year growth pineapple field with 18 percent maximum slope. Table 3 shows the width, depth, density and volume of rills and/or gullies. Pineapple growth age is a time indicator showing how often its field experienced rainy seasons, and when the soil erosion began, because old pineapples are removed from the fields every three years. Simultaneously, fields are prepared using a tractor to plant pineapple saplings at the beginning of the rainy season. Therefore, we can estimate soil erosion rates of pineapple fields. We estimated the soil erosion rate at the EP1 plot to be 49.4 m^3/ha/yr and that at the EP2 plot to be 116.3 m^3/ha/yr (Table 3). These soil erosion rates also can be shown to be 69 t/ha/yr (EP1) and 163 t/ha/yr (EP2) because the soil bulk density can be assumed to be 1.4 t/m^3 (Sakuma *et al*., 2002).

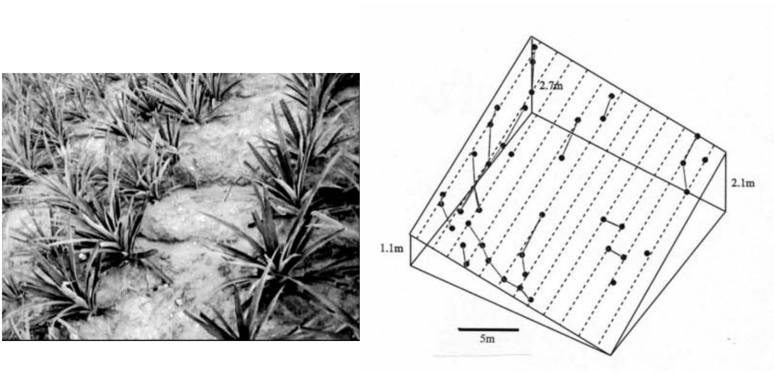

Fig. 13 Rill erosion at the one-year-growth pineapple field (EP1).
●—● Rill erosion. ······· Middle of planting rows.

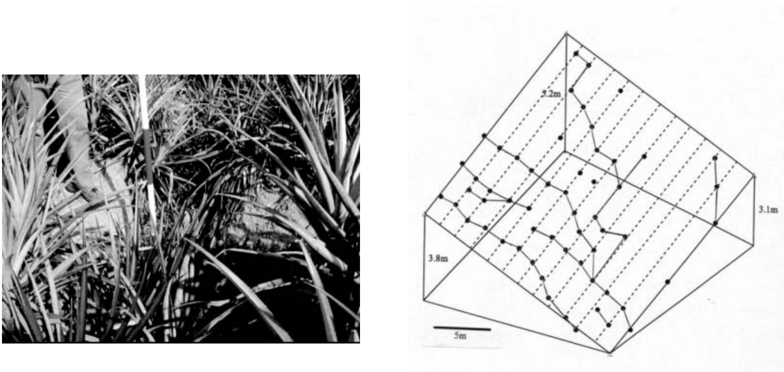

Fig. 14 Rill and gully erosion at the three-year-growth pineapple field (EP2).
●—● Rill or gully erosion. ······· Middle of planting rows.

Table 3 Width, depth, density and volume of the rill and/or gully in pineapple fields.

Plot name	Crop age	Maximum slope (%)	Rill and gully Density (m/m^2)	Width (m) Mean	Width (m) Range	Depth (m) Mean	Depth (m) Range	Volume (m^3/ha)
EP1	Pineapple (1year)	11	0.145	0.55	0.32- 0.69	0.12	0.05- 0.25	49.4
EP2	Pineapple (3years)	18	0.231	0.76	0.27- 2.20	0.31	0.08- 0.68	348.9

DISCUSSION

Forest Conversion to Cultivated Lands and Relationships with Soil Erosion

As previously mentioned, cultivated lands modify site hydrology by decreasing the infiltration capacity compared to forestlands, as demonstrated by the fact that forestlands have significantly higher final infiltration rates (44 to 160 mm/hr) than crop fields (5 to 39 mm/hr). Since strong rainfall intensity of tropical regions easily exceeds the infiltration capacity of cultivated lands, water accumulates on the soil surface and runs down as a Horton overland flow. The overland flow causes sheet, rill, and gully erosion. Thus, cultivated lands converted from forests are more susceptible to erosion than forestlands. In particular, severe erosion appears to occur during the land-clearing processes and in the initial few years following cropland establishment because of rapid storm runoff caused by the modification of site hydrology, and sediment produced on disturbed areas within the cultivated land. Therefore, sediment enters the stream during storm events from even lowland areas in the initial few years following forest clearing for establishing cultivated lands.
Such a huge amount of water and sediment entering the stream could cause the channel deformation. Also, the forest clearing on riparian areas could strongly affect its deformation. After that, the sediment entering the stream, coupled with the sediment produced by in-channel processes such as the bank erosion, could be transported downstream for a long time (Fig. 5). In brief, the effect of soil erosion caused by the conversion of forests to cultivated lands could have still propagated to the off site areas.

Recent Dynamic Cultivation Changes and Relationships with Soil Erosion

In the last decade, dynamic cultivation changes have occurred on the converted land related to a shift to a more profitable cash crop culture. As mentioned, typical soil erosion problems due to recent dynamic cultivation changes have occurred in pineapple fields of the sloping area in the Tha Khoei sub-basin because of the unique style of pineapple cultivation. For example, soil erosion rates of EP1 and EP2 plots indicate 69 and 163 t/ha/yr. These values far exceed the soil-loss tolerance levels, which are about 2 to 11 t/ha/yr (Troeh *et al.*,1980). Such severe soil erosion reduces pineapple productivity through reducing the availability of water, nutrients and organic matter. This is a main reason for promoting changes from pineapples to other crops, including fallow fields. Also this leads to expansion of the deforestation to the steeper sloping areas to develop new pineapple fields. As a result, more severe soil erosion is occurring in these areas. This suggests that a vicious cycle of watershed degradation may have already begun in some pineapple fields of the sloping area in the Tha Khoei sub-basin.
In relation to sediment production, we should also note another type of soil erosion due to inappropriate agricultural practices. For instance, the bank erosion near the IF 4 site was caused by the accordance of the direction in both floodplain's slope and cassava rows (Fig. 12).

Sediment Delivery in the Lam Phachi River

Figure 15 illustrates the relationship between the 1980s and the 1990s in the daily suspended sediment concentration at the K17 hydrological station of the Royal Irrigation Department (Figs. 1 and 2). As shown in Fig. 15, the concentration in the 1980s is significantly higher than in the 1990s. This suggests that the sediment produced by soil erosion due to recent dynamic cultivation changes, such as the expansion of pineapple fields to sloping areas, may not have reached streams yet because it could be trapped by irrigation ponds created at the mountain foot and lowland areas to enhance crop productivity over rain-fed farming (Marutani *et al*., 2002). Conversely, the sediment produced by the conversion of forests to cultivated lands in the entire basin could spread rapidly to streams during an initial decade following cropland establishment. Moreover, such past sediment disturbance in the watershed may have affected recent channel processes in such a way that the primary sediment entering streams, coupled with the secondary sediment produced by bank erosion etc., is transported to downstream. According to Kimura *et al.* (2002), the section located 30 to 43 km from the river mouth is categorized as a lateral migration with massive sedimentation. Changes in the channel width and the longitudinal profile resulting from soil erosion caused by the conversion of forests to cultivated lands two or three decades ago, suggest that primary and secondary sediment has been accumulated in this section (Figs. 2 and 5).

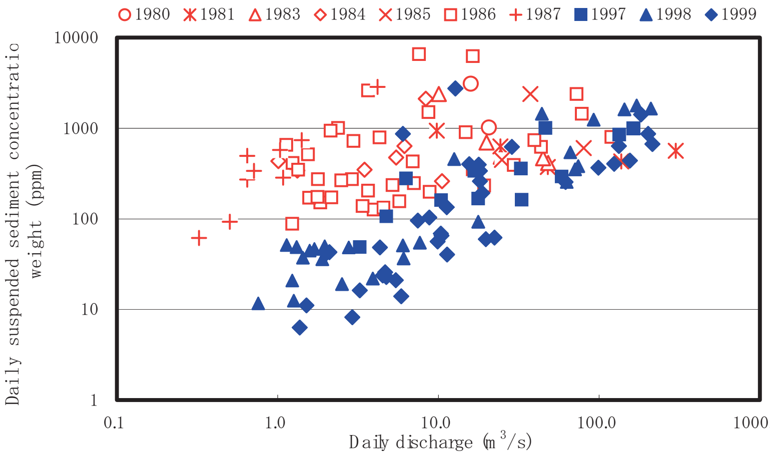

Fig. 15 Comparison of the daily suspended sediment concentration in the 1980s with the 1990s as a function of daily discharge.

CONCLUSIONS

Satellite image analysis revealed two stages of land use changes in the Lam Phachi watershed. The first stage is forest conversion to cultivated lands that was practiced in the entire basin two or three decades ago, and the second stage is the dynamic cultivation changes that occurred on the converted lands related to a shift to a more profitable cash crop culture since the 1990s. Infiltration tests clarified that crop fields have significantly lower final infiltration rates (5 to 39 mm/hr) than forestlands (44 to 160 mm/hr). Therefore, cultivated lands

converted from forests are more susceptible to erosion than forestlands. Particularly, severe erosion may have occurred during the land-clearing processes and in the initial few years following cropland establishment because of a marked increase in rapid storm runoff caused by the modification of site hydrology and the soil disturbance within the cultivated land.
Soil erosion surveys conducted at the second stage sites for land use changes revealed that severe soil erosion problems have occurred on some pineapple fields in sloping areas, demonstrated by soil erosion rates of survey plots of 69 and 163 t/ha/yr, which are much higher than the soil-tolerance levels (2 to11 t/ha/yr). A vicious cycle of watershed degradation may have begun in some pineapple fields in sloping areas of the Tha Khoei sub-basin. Regarding sediment delivery, the analysis of suspended sediment monitoring data suggests that sediment produced by soil erosion in the second stage may not have reached streams yet because irrigation ponds to support the recent cash crop culture may trap the sediment. Conversely, the sediment produced by deforestation in the first stage could rapidly spread to streams in an initial decade following cropland establishment. Such past sediment disturbance in the watershed may have affected recent channel processes in such a way that the primary sediment entering streams, coupled with the secondary sediment produced by bank erosion etc., is transported downstream.

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