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Human Impact on Soil Erosion of the Lam Phachi River Basin
- From a Viewpoint of Infiltration Capacity -

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Abstract

This paper focuses on soil erosion problems in the Lam Phachi River basin. The10-minute interval rainfall data in the target area of the upper basin suggested that the rainfall pattern was characterized by strong intensity and short duration. As a result of infiltration tests, the forestlands had higher final infiltration rates (44-160 mm/hr) than the pineapple and cassava fields (5-39 mm/hr), though they had considerable rate variation depending on the soil characteristics. Thus, strong rainfall intensities and low infiltration rates caused severe soil erosion (69, 163 t/ha/yr) in some areas of the pineapple fields on gentle slopes in the target area. Vegetation surveys revealed that forests on the fringe of croplands were secondary forests caused by frequent and intensive disturbance due to human activities such as logging and fires. This study indicated two stages for soil erosion problems in the basin. The first stage is that the forest conversion to cultivated lands was practiced in the entire basin during the past two or three decades. The second stage is that dynamic cultivation changes have occurred on the converted land related to a shift to a more cash-crop-oriented culture since the 1990s. Recent dynamic changes in cultivation might have already caused the vicious cycle of watershed degradation in some areas of the basin, e.g., pineapple fields on gentle slopes of the upper region. We now need protection measures against accelerated erosion, and appropriate agricultural practices in the context of sustainable agricultural production and environmental protection to maintain the sound watershed.

Keywords: soil erosion, infiltration capacity, human impact, pineapple field

1. INTRODUCTION

The conversion of forests to cultivated lands can lead to soil erosion and declining yields, and agricultural changes shifting from subsistence to cash crops can also lead to increasing erosion and declining productivities. These conversions and changes result from natural degradation hazards, the direct and underlying causes of watershed degradation. The natural degradation hazards are conditions of the natural environment which lead to high susceptibility to degradation, e.g., steep slopes, high intensity rainfall and drought in the dry season. The direct causes include deforestation of fragile land making it unsuitable for sustained agricultural use, shifting cultivation without adequate fallow periods, and failure to adopt soil conservation management practices. The underlying causes are land shortages, land tenure, economic pressures, poverty, and population pressures (FAO, 1994). Thus human-induced impacts are strong driving forces for watershed degradation. Soil erosion can be the most serious mechanism of watershed degradation because it adversely affects not only agricultural productivity through reducing the availability of water, nutrients, and organic matter, but it also causes serious off-site effects, i.e. eroded sediments fill riverbeds, lakes, and reservoirs, significantly reducing their roles for floods, irrigation, hydropower, fisheries, and the environment. In the Lam Phachi River basin, forests were converted to cultivated lands in the entire basin during the past two or three decades. Recently, dynamic cultivation changes have occurred on the converted land related to a shift to a cash-crop culture. These changes might have caused soil erosion problems in croplands, particularly pineapple fields on gentle slopes in the upper region of the basin.

This paper describes the infiltration capacity, soil characteristics, and erosion rates in adjacent plots of the forestland and the cropland, particularly pineapple fields, and the human impact on soil erosion to clarify the mechanism of the watershed degradation of the Lam Phachi River basin.

2. STUDY AREA

The Lam Phachi River drains a 2620 km^2 basin whose ridge is the Myanmar border in the western part of Thailand (Fig. 1). It runs north and joins the Huai Tha Khoei River, the largest tributary at Ban Tha Khoei, the center of the basin. The relief of the basin declines from 1020 m in the headwaters to 30 m at the confluence with the Khwae Noi River. The basin receives an average of 1130 mm rainfall annually, 90 percent of which falls during the rainy season between May and November, and 10 percent falls 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 basin. Sedimentary rocks of the Quaternary Period underlie the lowland of the basin. 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).

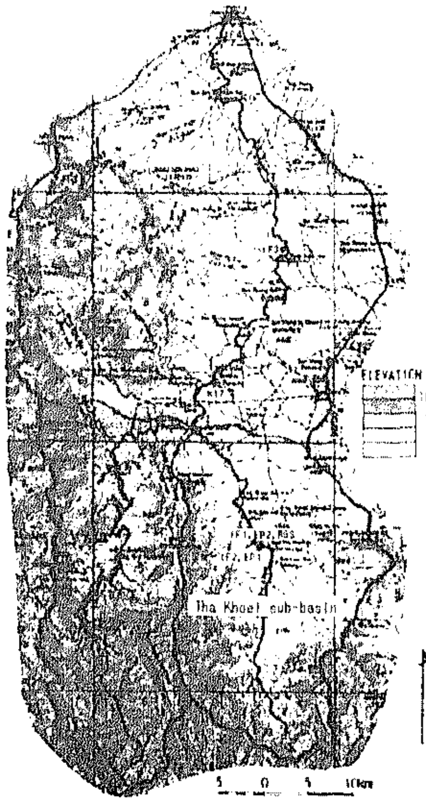

Fig. 1 Map showing the study area,
IF1-IF4; Infiltration capacity test site,
EP1-EP2; Soil erosion measurement plot,
RGS; Rain gage station,
K17; Hydrological monitoring site of RID

3. INFILRATION CAPACITY, RAINFALL INTENSITY AND SOIL EROSION

Soil erosion in the cropland mostly resulted from the Horton overland flow that is produced when the rainfall rate exceeds the ability of the soil to absorb water (Kirkby, 1978).

Therefore, the infiltration capacity of soil and rainfall intensity are the most important physical factors for soil erosion.

3.1 Site Selection

3.1.1 Infiltration capacity test, soil and vegetation surveys

To compare the infiltration rate of the forestland with the cropland, we selected four sites (IF1 to IF4) along the Lam Phachi River and the Huai Tha Khoei River that is the main tributary (Figs. 1 and 2). Each site has two adjacent plots to test infiltration rates of forestland and cropland, with the exception of the IF4 site. Main crops of the basin are pineapple, sugarcane, cassava, maize and vegetables. Pineapple is cultivated on the gentle slope areas such as foothills, rather than the flat areas such as flood plains, whereas the other crops are cultivated on the flat areas. In the IF1 and the IF2 sites that are on hilly areas, pineapple fields were selected to compare with the infiltration rate of the forestland, whereas in the IF3 site on the flood plain, sugarcane fields were selected. In the IF4 site on the flood plain, only the infiltration rate of the cassava field was tested.

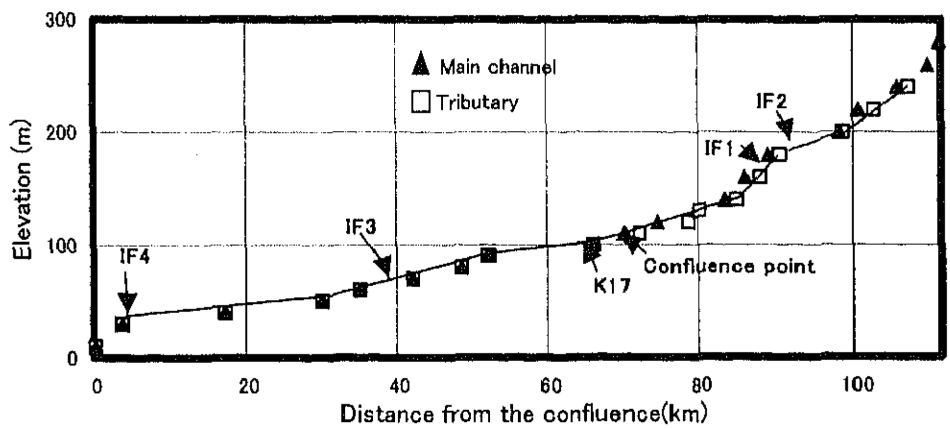

Fig. 2 Longitudinal profile of the Lam Phachi River

We also conducted a soil survey (IF1 to IF4) and a vegetation survey (IF1 to IF3) to investigate the influences of soil and vegetation characteristics on the infiltration capacity. Since forest surrounds the crop fields, pineapple fields are thought to have a similar soil condition to the forest before logging, and their structure might give us the intensity and the frequency of artificial disturbances in the forests. The tests and surveys were carried out from late July to early August 2001.

3.1.2 Rainfall intensity and soil erosion

We set the rain gage station (RGS) in the center of the Huai Tha Khoei sub-basin in early October 2000 to obtain the short interval rainfall data (Fig. 2). Main crops of the upland areas in the Huai Tha Khoei River sub-basin, the research target area for investigating the human impact on soil erosion, are pineapple, sugarcane, and cassava. Since we can find soil erosion in a lot of the pineapple fields on the sloping areas, we set two plots (EP1, EP2) on such sites near the RGS and surveyed the rill and gully erosion in late November 2000, the end of the rainy season (Fig. 1).

3.2 Methods

3.2.1 Infiltration capacity test, soil and vegetation surveys

We measured the infiltration capacity using a cylinder type infiltrometer. To avoid divergent flow, a 40 cm diameter infiltration ring was put inside a 60 cm ring. The outer ring was flooded simultaneously with the inner ring to serve as a buffer to help ensure one-dimensional vertical flow from the inner flow. The rate of water depth decrease in the inner ring was then measured and maintained at a roughly constant depth for the duration of the test.

However, the infiltration rate measured by the infiltrometer was generally higher than that of natural rainfall.

We also surveyed the soil profile, texture and hardness by digging a trench near the infiltration capacity measurement site. The soil hardness of each horizon in the soil profile was measured using a push-cone type soil hardness meter. The soil was then sampled from each horizon, and its particle size was analyzed in the laboratory to classify the soil texture, which was determined using the classification standardized by the U.S. Department of Agriculture.

We set up three vegetation survey plots in the forest adjacent to the pineapple fields (IF1 and IF2), one survey plot in the forest adjacent to a sugarcane field (IF3), and one survey plot in the forest in the mountain area considered to be covered by the original forest (MD). In each survey plot, all stems higher than 1m were identified to the species level, and the heights of these stems were measured. Stems with a height over 1.3m were measured at DBH (1.3m height).

3.2.2 Rainfall intensity and soil erosion

To automatically obtain the short-interval rainfall, we used a tipping bucket rain gage and a data logger that was set to 10-minute intervals. To investigate the form and the volume of soil erosion that occurred in the pineapple fields, we surveyed the patterns, and the width, the depth, and the length of the rills and gullies in the about 20×20 m plots.

3.3 Results and Discussions

3.3.1 Infiltration capacity and soil characteristics

The results of soil profile, texture and hardness surveys at the trench near the infiltration capacity test site are shown in Figs. 3 to 9. The results of infiltration capacity tests using a cylinder-type infiltrometer are shown in Figs. 10 to 13. Though many factors influence the shape of the infiltration capacity curve, the most important controls are rainfall characteristics (intensity, duration, and drop size), soil characteristics (texture, structure, initial moisture content, clay mineralogy, and condition of the soil surface before rainfall), vegetation and land use. As shown in the infiltration capacity curves obtained by the tests (Figs. 10 to 13), the infiltration rate is high in early stages, but tends to decrease monotonically and asymptotically approach a constant rate that is often termed the final infiltration rate. The early stage of curves shows that water penetrates as fast as it arrives, and the water supply rate determines the infiltration rate; i.e., the process is supply-controlled (Hillel, 1998). In contrast, the latter and final stages show that the soil controls the rate of infiltration, either at the surface or within the profile, and the process becomes soil-controlled (Hillel, 1998). Thus, the latter process determines the actual infiltration rate.

Comparing the final infiltration rate of forestland with that of the pineapple field at the IF1 site, the rate of forestland (160 mm/hr) is considerably higher than that of pineapple field (28 mm/hr)(Fig. 10). The IF1site is located at the foot of hilly land. Both soils are considerably deep (more than 80 cm in depth) and are similar in soil profile, texture and hardness (Figs. 3 and 4). At the IF2 site, the rate of forestland (44 mm/hr) is not so different from the pineapple field (39 mm/ hr) as compared with the IF1 site (Fig. 11) The IF2 site is located at the top of hilly land. Neither soil is so deep (30-40 cm in depth), and soils are similar in soil profile, texture and hardness (Figs. 5 and 6). At the IF3 site, the rate of forestland (130 mm/hr) is considerably higher than that of the sugarcane field (20 mm/hr) (Fig. 12). The IF3 site is located on the floodplain near the river. Judging from the soil texture and hardness, the forest plot for the infiltration test may be selected on a sand dune of the former river channel (Fig. 7). 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) (Figs. 7 and 8). The IF4 site containing the plot to conduct the infiltration test for the cassava field, is located on the floodplain just above the confluence of the Khwae Noi River. The rate of the cassava field (5 mm/hr) is quite low (Fig. 14). The soil profile, texture and hardness of the field suggest that indurated layers (called hardpans) might be formed in the layer below 20 cm depth from the surface (Fig. 9). Hardpans cause a low final infiltration rate.

As previously mentioned, at the IF1 site the final infiltration rate of the forest plot is considerably higher than that of the pineapple plot. At the IF2 site, however, the difference of the final rate between the forest plot and the pineapple plot is not significant. Since the IF1 site differs from the IF2 site in soil depth, but not in the other soil characteristics, this might suggest that the first factor controlling the final infiltration rate is soil depth.

Soil prifile 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

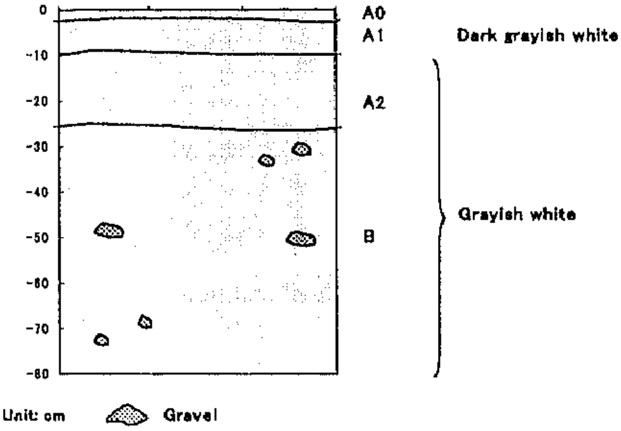

Fig. 3 Soil characteristics of the secondary forest at the IF1 site

Soil prifile 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≒60%	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

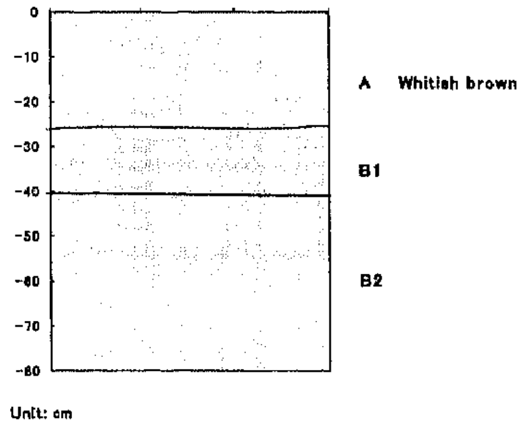

Fig. 4 Soil characteristics of pineapple field at the IF1 site

Soil prifile of secondary forest at IF2F
Survey date: July 30, 2001

Soil hardness

Soil layer	Soil hardness
A	30 kg/cm^2
B1	9 kg/cm^2
B2	12 kg/cm^2

Soil texture

Sample No.	Sand %	Silt %	Clay %	Texture
A(0-10)	71.87	18.09	10.05	Sandy Loam
B1(10-20)	74.22	16.56	9.22	Sandy Loam
B2(20-30)	75.36	16.36	8.28	Sandy Loam

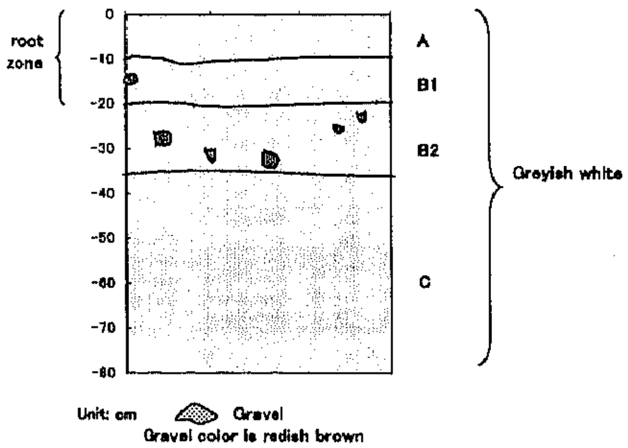

Fig.5 Soil characteristics of the secondary forest at the IF2 site

Soil prifile of pineapple field
(second or thied year growth) at IF2P
Survey date: July 30, 2001
Slope angle: 5 degree

Soil hardness

Soil layer	Soil hardness
A	10 kg/cm²
B1	20 kg/cm²
B2	15 kg/cm²

Soil texture

Sample No.	Sand %	Silt %	Clay %	Texture
A(0-7)	70.88	18.36	10.75	Sandy Loam
B1(7-15)	70.79	24.71	4.50	Sandy Loam
B2(15-25)	72.35	17.71	9.94	Sandy Loam
B2(25-35)	75.88	15.72	8.40	Sandy Loam

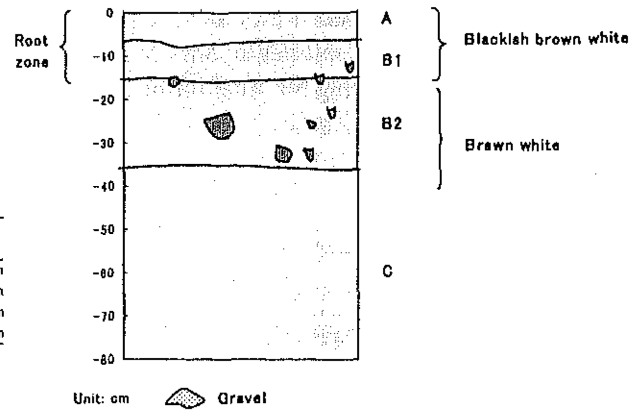

Fig. 6 Soil characteristics of the pineapple field at the IF2 site

Soil prifile of secondary forest at IF3F
Survey date: July 31, 2001

Soil hardness

Soil layer	Soil haredness
B1	0.5 kg/cm²
B2	1.9 kg/cm²
B3	0.9 kg/cm²

Soil texture

Sample No.	Sand %	Silt %	Clay %	Texture
A(0-6)	88.309	6.579	5.112	Sand
A2(6-10)	92.087	4.128	3.785	Sand
B(10-30)	97.404	0.795	1.801	Sand
B(30-35)	97.514	0.285	2.201	Sand
B(50-70)	97.887	0.12	1.993	Sand
B(70-90)	97.199	0.035	2.767	Sand

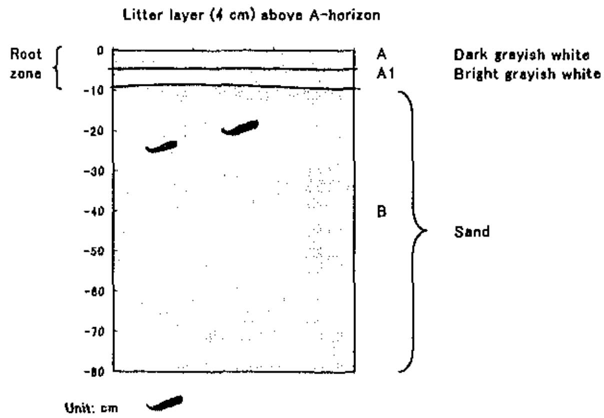

Fig. 7 Soil characteristics of the secondary forest at the IF3 site

Soil prifile of sugarcane field at IF3S
Survey date: July 31, 2001

Soil hardness

Soil layer	Soil hardness
B1	2 kg/cm²
B2	10 kg/cm²
B3	22 kg/cm²

Soil texture

Sample No.	Sand %	Silt %	Clay %	Texture
B1(0-10)	79.95	13.67	6.38	Loamy Sand
B2(10-35)	81.82	12.39	5.79	Loamy Sand
B3(35-55)	66.89	23.82	9.29	Sandy Loam
B3(55-75)	58.83	28.86	12.31	Sandy Loam

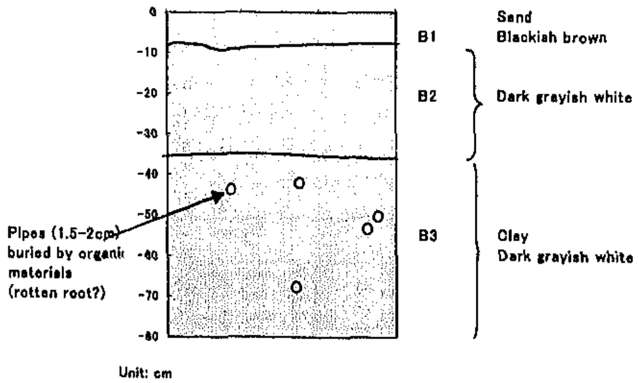

Fig. 8 Soil characteristics of the sugarcane field at the IF3 site

Soil prifile of cassava field at IF4C
Survey date: August 1, 2001

Soil hardness

Soil layer	Soil hardness
A(0~20)	4 kg/cm^2
B(20~30)	38 kg/cm^2
B(30~50)	50 kg/cm^2

Soil texture

Sample No.	Sand %	Silt %	Clay %	Texture
A(0~20)Brigh·	77.85	16.97	5.19	Loamy Sand
A(0~20)Dark	78.19	16.03	5.78	Loamy Sand
B(20~30)	77.41	17.63	4.96	Loamy Sand
B(30~50)Blac	75.00	16.58	8.42	Sandy Loam
B(30~50)	78.11	16.48	5.41	Loamy Sand

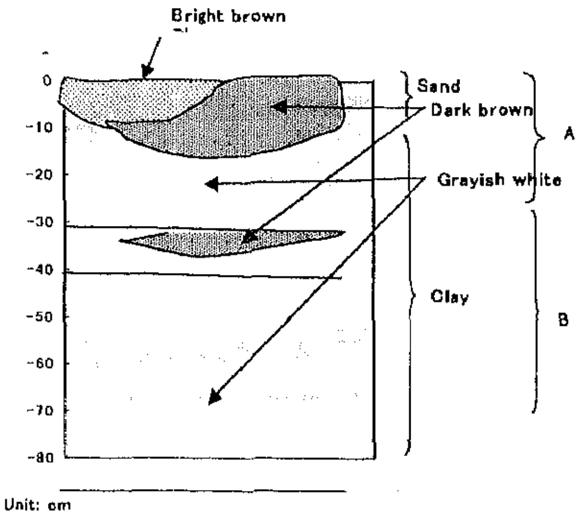

Fig. 9 Soil Characteristics of the cassava field at the IF4 site

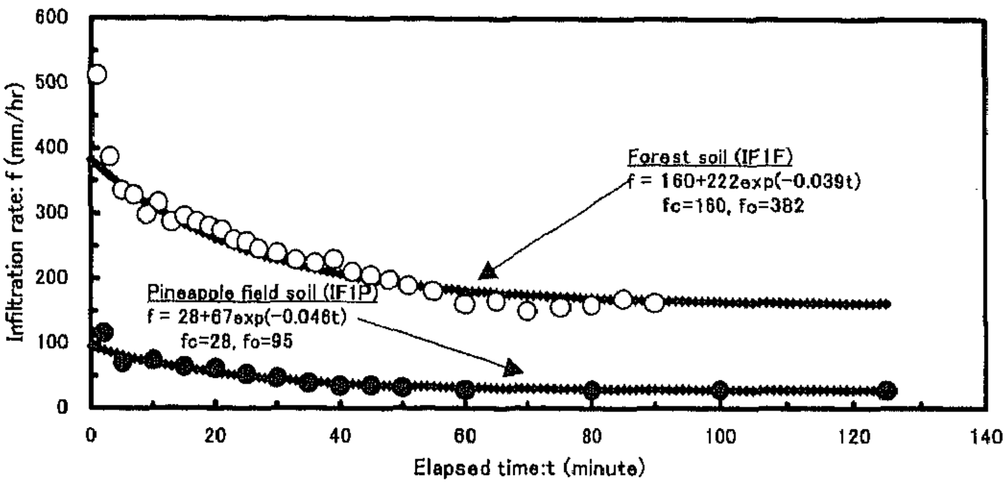

Fig. 10 Infiltration capacity curves of the forestland and the pineapple field at the IF1 site
f: Horton equation, fc: final rate, fo: initial rate

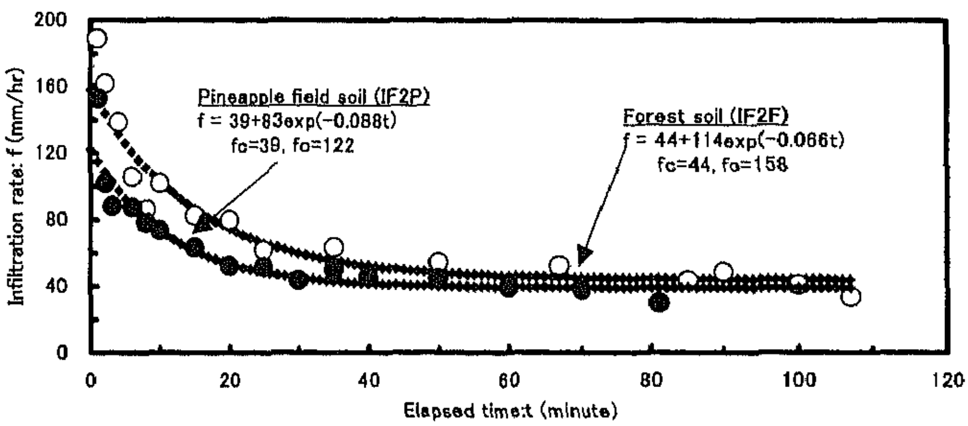

Fig. 11 Infiltration capacity curves of the foretland and the pineapple field at the IF2 site
f: Horton equation, fc: final rate, fo: initial rate

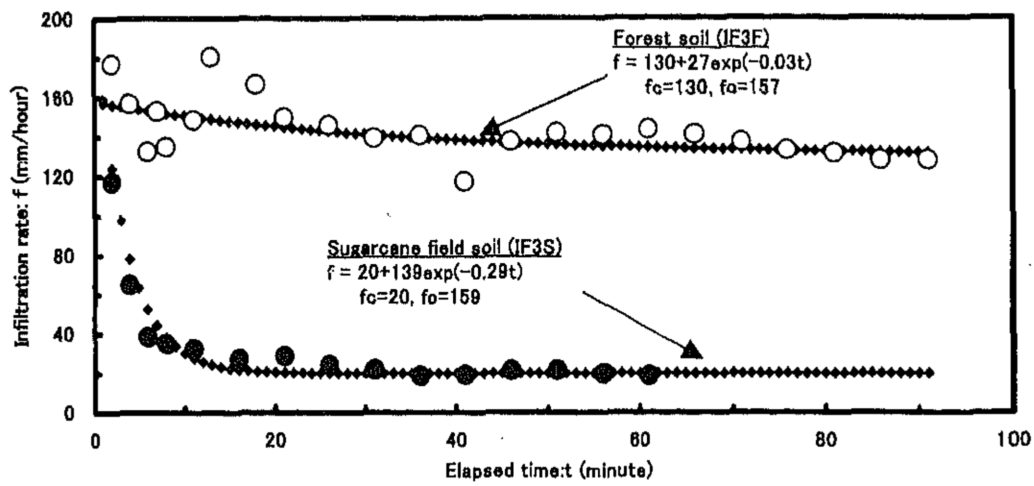

Fig. 12 Infiltration capacity curves of the forestland and the sugarcane field at the IF3 site
f: Horton equation, fc: final rate, fo: initial rate

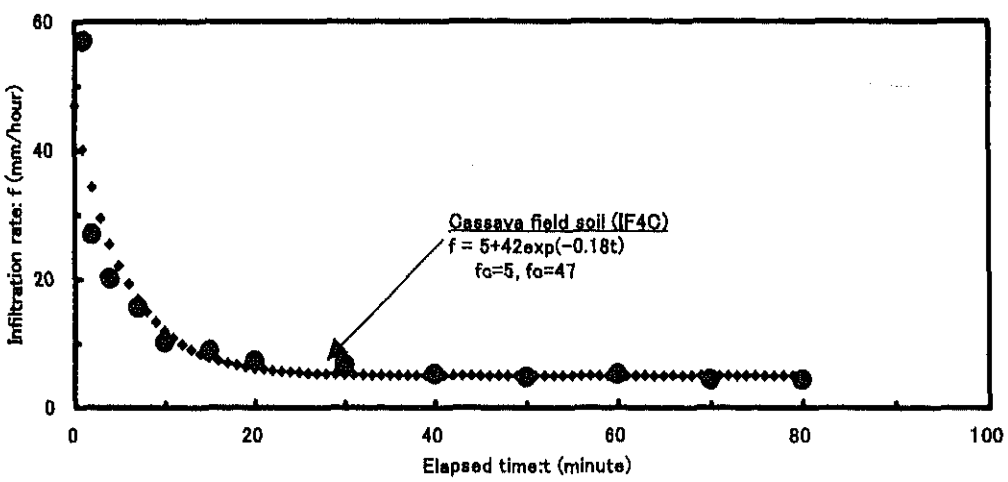

Fig. 13 Infiltration capacity curve of the cassava field at the IF4 site
f: Horton equation, fc: final rate, fo: initial rate

Overall, the forestlands have higher final infiltration rates than the pineapple and cassava fields, though they have considerable variation in the rate depending on the soil characteristics. This tendency can be found in many other measurements of infiltration capacity. According to Inthasothi and Chunmao (1976), the final infiltration rate of the evergreen forest area was 48 mm/ hr, compared to the old cultivated area, which means that the shifting cultivation was practiced, resulting in the smaller value of 20 mm/hr in the final rate. These values were obtained using the method of applying water in the field plot at Mae Thalai watershed, Chiengdao, Thailand. Nakano (1976) summarized the results of the infiltration test in Japan using the method of applying water in the field plot in various land use areas of Iwate Prefecture. According to his summarization, the final infiltration rate of forestland was 250-270 mm/hr. Conversely, the final rate of the landslide scar and the unpaved road were 99 and 11 mm/hr respectively. Many field tests suggest that the forestland generally has a higher final infiltration rate than cultivated land and bare land. Thus forest cover has a strong influence on the infiltration capacity. However, we need to conduct further research to understand the mechanism causing the difference.

3.3.2 Rainfall intensity

In the Lam Phachi River basin, 90 percent of the annual rainfall falls during the rainy season between May and November. Rainfall in September and October is much higher than other months of the rainy season. Figure 14 shows hourly rainfall at the RGS from September 10 to October 20, 2000, and Fig. 15 illustrates 10-minute rainfall at the RGS from September 27 to October 1, 2000. The rainfall pattern is characterized by strong intensity and short duration. This suggests that croplands, which have the lower value in the final infiltration rate, are susceptible to soil erosion because the Horton overland flow occurs easily due to strong rainfall intensity, but that the eroded sediment load could be not transported any distance due to short rainfall duration.

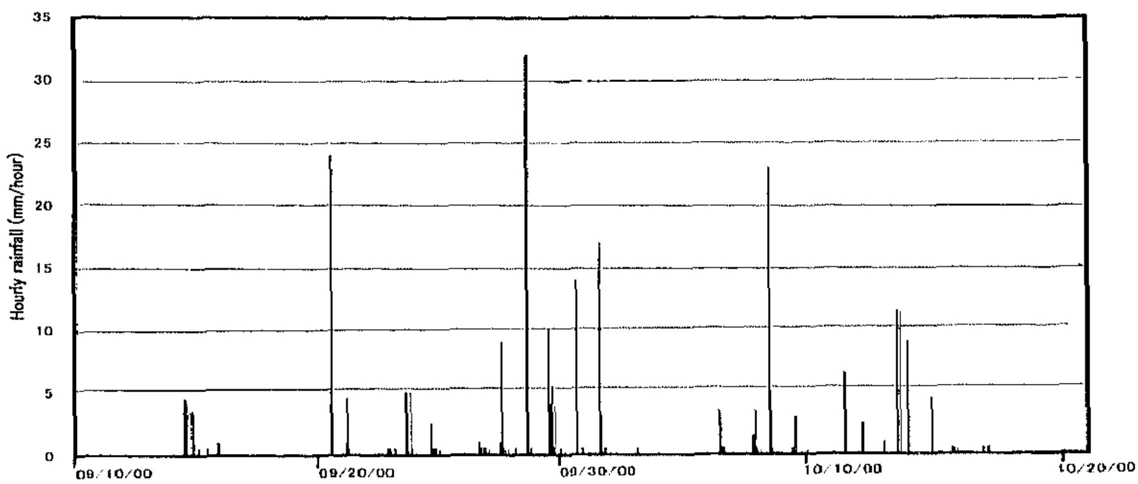

Fig. 14 Hourly rainfall from 10 September to 20 October 2000 at RGS

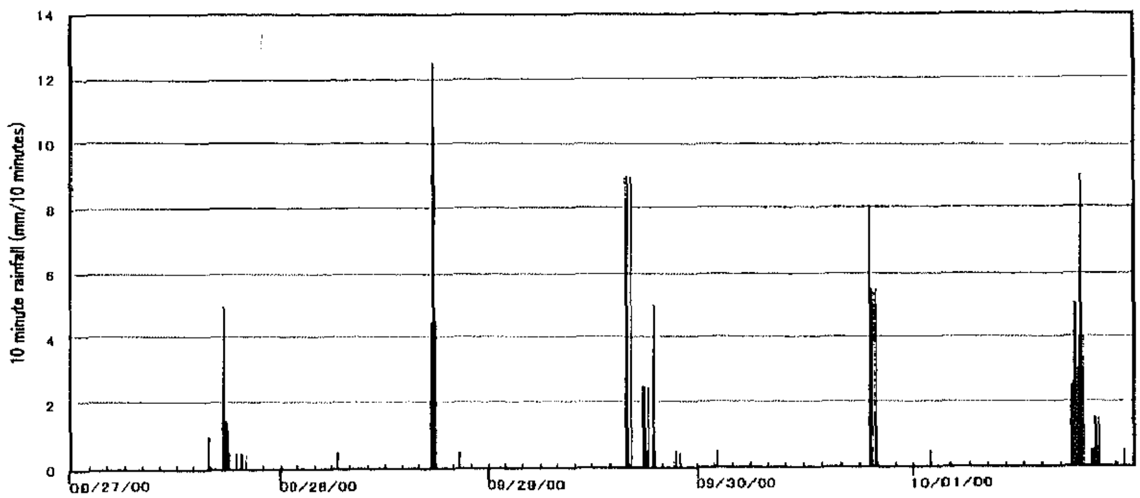

Fig. 15 10 minute rainfall from 27 September to 1 October 2000 at RGS

3.3.3 Soil erosion

Figure 16 shows rill erosion at the EP1 plot, a one-year growth pineapple field with 11 percent maximum slope, and Fig. 17 shows rill and gully erosion at the EP2 plot, a three-year growth pineapple field with 18 percent maximum slope. Both plots are selected in the most severe soil erosion area in the target research area. The pineapple growth age is a time indicator showing how often its field experienced rainy seasons, and when the soil erosion in its field began. Every three years, old pineapples are removed from the fields, and simultaneously field preparation using a tractor is completed to plant young pineapple plants at the beginning of the rainy season. This preparation results in an almost flat field condition. It was estimated that the EP1 plot experienced one rainy season and that the EP2 plot experienced three.

The mean width of rills and gullies in the EP1 (EP2) plot is 0.55 m (0.76 m). The mean depth of rills and gullies in the EP1 (EP2) plot is 0.12 m (0.31 m)(Table 1). Considering the range of width and depth (Table 1), rill erosion in the first-year-growth pineapple field caused by the rainfall of the first rainy season could develop into gully erosion by the rainfall of the second and the third rainy season. This change could promote the extension and the connection of rills and/or gullies and result in higher density of rills and gullies (Figs. 16 and 17, Table 1). If we divide the volume of rill and gully at the EP1 and the EP2 plots by the number of rainy seasons, we can roughly estimate the annual soil erosion. Thus 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 1). These soil erosion rates also can be shown to be 69 t/ha/yr (EP1) and 163 t/ha/yr (EP2) if the bulk density of the soil is assumed to be 1.4 t/m^3.

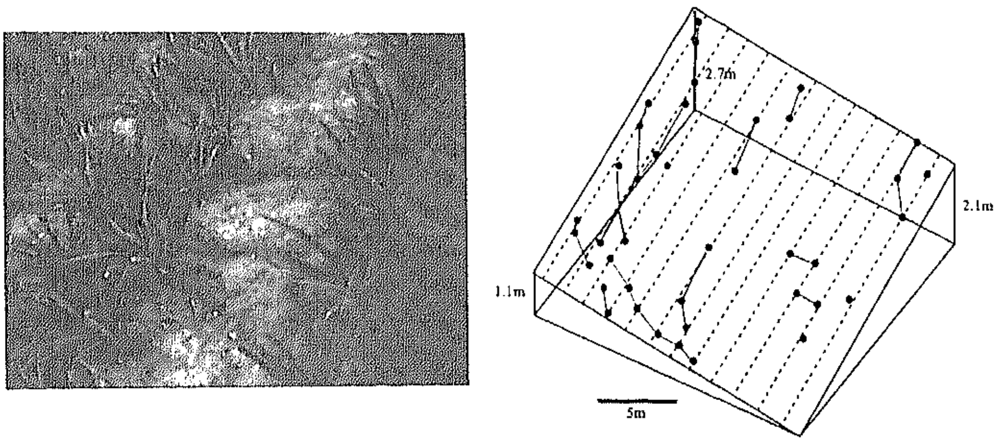

Fig. 16 Rill erosion at the pineapple field of one year growth (EP1)
●—● Rill erosion, ... Middle of planting rows

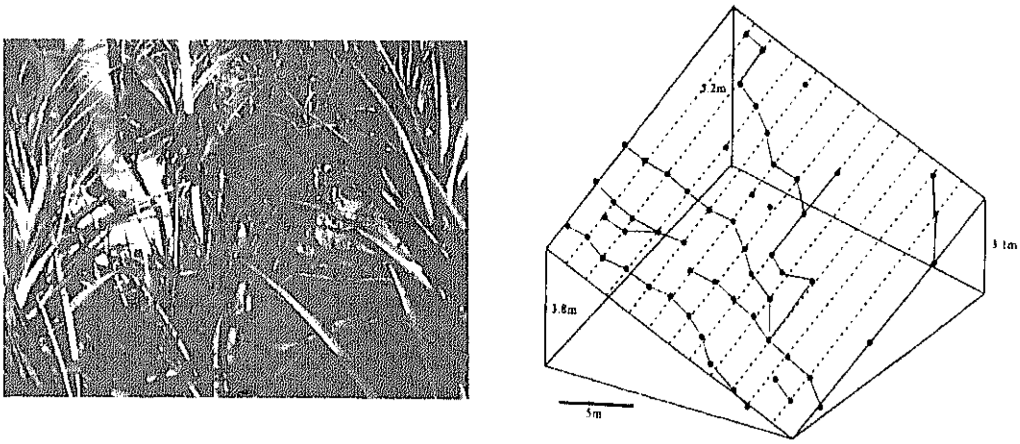

Fig. 17 Rill and gully erosion at the pineapple field of three year growth (EP2)
●—● Rill or gully erosion, ... Middle of planting rows

According to Sidle (2002), soil losses from conventional hillslope agriculture practices in

Southeast Asia are high. For example, for vegetable crops grown on moderate to steep hillsides, the highest levels of soil loss were 38-140 t/ha/yr. This occurred when cultivation was oriented up and down the hillslope, a typical practice in the region. According to Edwards (1993), soil loss in the bare land in Australia is reported to be 31- 87 t/ha/yr. Comparing these soil loss rates in Southeast Asia and Australia, soil erosion rates in the EP1 and EP2 plots of pineapple fields, which may show the most severe erosion in the research target area, can be ranked as the highest level. Another type of soil erosion caused by inappropriate agricultural practices can be seen in the downstream areas. For example, the bank erosion near the IK4 site was caused by the accordance of the direction in both floodplain's slope and cassava rows coupled with quite low infiltration capacity due to hardpans (Photo 1, Fig 9).

Table 1 Width , depth, density and volume of the rill and/or gully

Plot name	Crop age	Maximum slope (%)	Rill and gully					
			Density (m/m^2)	Width(m)		Depth(m)		Volume(m^3/ha)
				Mean	Range	Mean	Range	
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

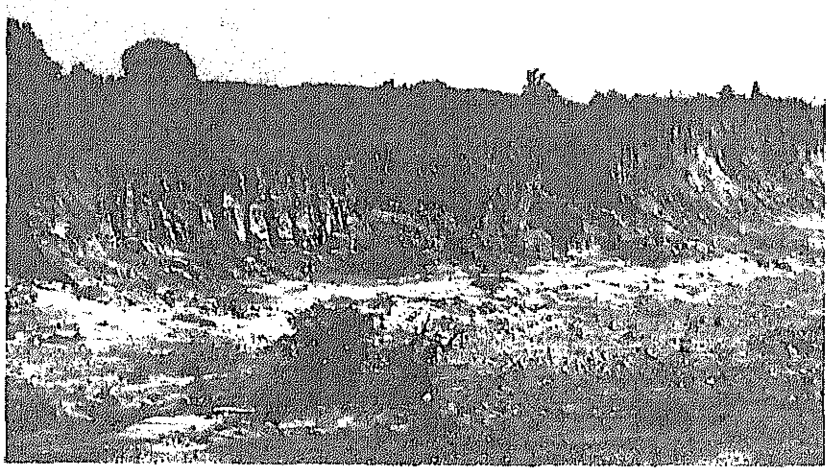

Photo 1 Bank erosion caused by inappropriate agricultural practices near the IF4 site

3.3.4 Vegetation survey

The density of trees varied among plots from 622 trees/ha to 25,600 trees/ha (Table 2). BA was varied among plots. Both the density and BA were lowest in the MD plot. The mean BA, which seemed to reflect the successional stage, was lower in the IF2(1) plot and in the IF2(2) plot, and highest in the MD plot. The MD plot had the highest values of mean DBH and maximum DBH, while the IF2(1) and IF2(2) plots had lower values than other plots (Table 2). The same results were obtained for mean H and maximum H. The species composition was different among plots (Table 3). In the IF2(1) plot *Acacia* and *Clestanthus denudatus* were dominant, and in the IF2(2) plot *Acacia* sp. and *Croton roxburghii* were the dominant tree species. *Callicarpa longifolia* (*Dalbergia volubilis*) dominated the stand in the IF1 plot (IF3 plot). Only two species, *Dalbergia volubilis and Fernandoa adenophylla*, were recorded in the IF3 plot. *Ficus hispidata* and *Harrisonia perforata* exhibited the higher density in the MD plot. The number of species per plot was higher in the MD plot, in which seven tree species were identified. Other plots had only two to four species per plot. All stand had the uni-modal DBH frequency distribution (Fig. 18). The mode of DBH frequency was 1-2cm, for the IF2(1) plot, 1-2cm for the IF2(2) plot, 4-6cm for the IF3 plot, 4-5cm for the IF1 plot, and 10-15cm for the MD plot. The MD plot exhibited a less prominent peak of DBH frequency than other plots.

Table 2 Stand characteristics of each plot setup in the secondary stand

		IF1	IF2 (1)	IF2 (2)	IF3	MD
Plot size(m^2)		100	25	25	25	225
n(/ha)		1700	25600	12800	13200	622
BA(cm^2/ha)		28136.88	145311.2	70142.32	389972.1	80679.2242
Mean BA(cm^2)		16.55111	5.67621875	5.47986875	29.5433409	129.663039
DBH(cm)	Mean	4.38	2.38	2.26	5.75	11.1785714
	Max	7	5.4	7.8	11.6	23.7
Height(m)	Mean	4.59	3.22	3.48	7.39	9.77142857
	Max	6	5	5	10	16

Table 3 Species composition of each plot in the secondary forest

	Number of stems (/ha)				
Species	IF1	IF2(1)	IF2(2)	IF3	MD
Diospyros coaetanea	200				
Gmelina asiatica	500				
Caesalpinia sappan	1000				
Callicarpa longifolia		400			
Acacia sp		16000	2800		
Clestanthus denudatus		8400	400		
Ehetia laevis		400			
Wrightia arborea			1600		
Croton roxburghii			7600		
Dalbergia volubilis				12400	89
Fernandoa adenophylla				800	
Bridelia curtisii					44
Dalbergia volubilis var. volubilis					
Ficus hispidata					178
Harrisonia perforata					133
Lagerstroemia tomentosa					44
Polyalthia suberosa					89
Other species		400	400		44
Total	1700	25600	12800	13200	622

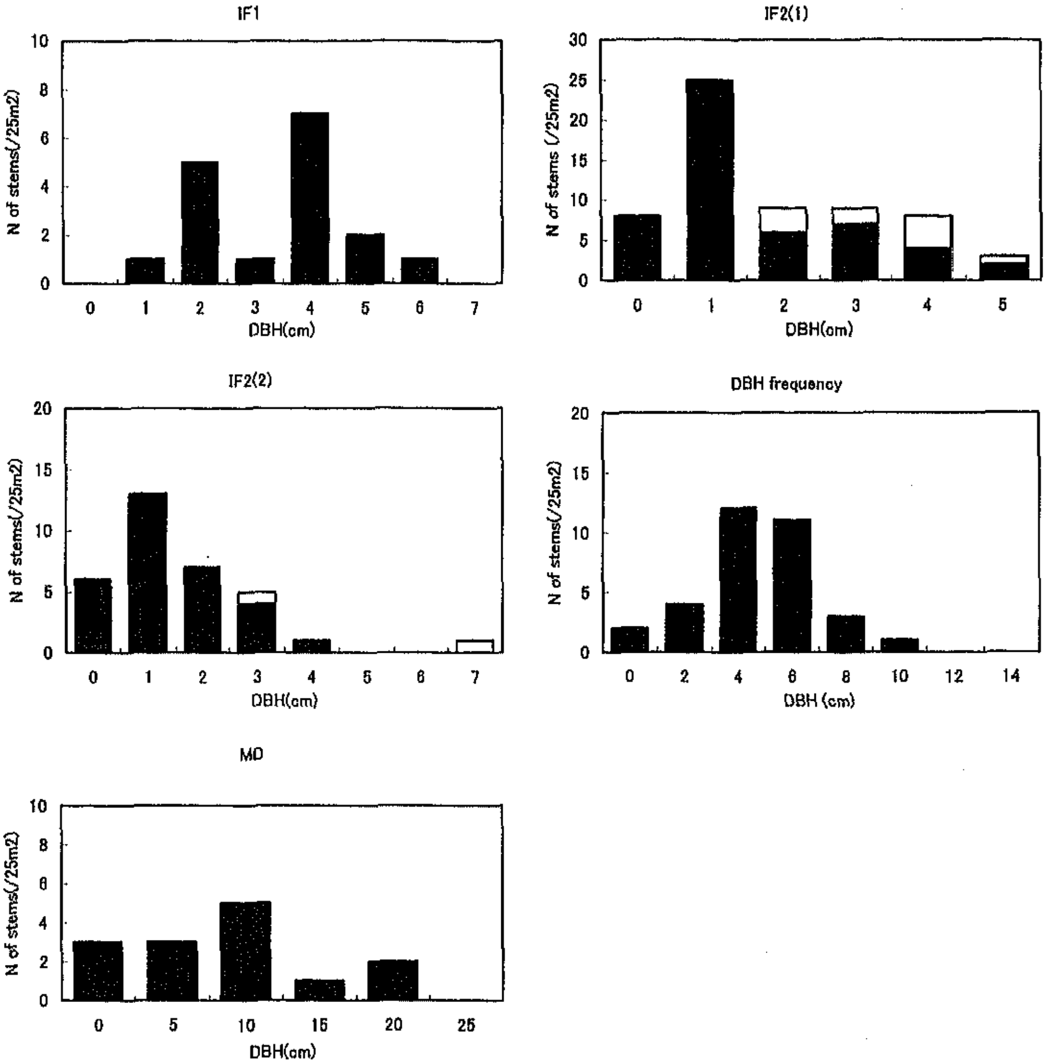

Fig. 18 DBH frequency of each plot
Closed bar and open bar indicate living stems and dead stems respectively

The species composition of each plot suggests that forests on the fringe of croplands are secondary forests. The density of trees is higher (622-25,600/ha) and the mean BA is much lower (5.5-129.7cm^2) in these secondary stands than in the natural mixed deciduous forest (171/ha, 1,005.8cm^2) in this region reported by Marod et al. (1999). Of the five plots investigated, the MD plot had the lowest density and highest mean BA, indicating the MD plot was in a successionally more developed stage than other plots. The MD plot located in the mountain area, and this plot were considered undisturbed by human activity, such as logging. However, other plots located adjacent to the arable fields suffered various human impacts, affecting these plots and setting these plots back to the early successional stage frequently. Those human impacts include logging for fuel woods, construction timbers, and the clear-cutting for shifting cultivation. Some trees in the IF2(1) had fire scars indicating past fire events. It seemed that such a difference in the disturbance history might cause the difference of stand structure between the MD plot and the four other plots.

With the exception of the MD plot, all the plots possessed a prominent unimodal distribution of DBH. The unimodal distribution of DBH or height was reported for the even-aged stand regenerated after the disturbance (Lorimer and Krug 1983, Palik and Pregitzer 1992). Thus, the size structure indicated that these secondary stands were even-aged stands composed from stems regenerated simultaneously after the disturbance, such as logging or fires. Also the mode of DBH frequency was smaller in all stands compared to that of natural stands. We could thus conclude that the secondary stands around the pineapple fields were immature and in the initial stage of stand development because of frequent and intensive disturbance by human activity, such as loggings or fires.

4. HUMAN IMPACT ON SOIL EROSION

4.1 Forest Conversion to Cultivated Lands

The conversion of secondary forests to cultivated lands has undoubtedly been the most widespread land use change in the Lam Phachi River basin during the past two or three decades (Fig. 19).

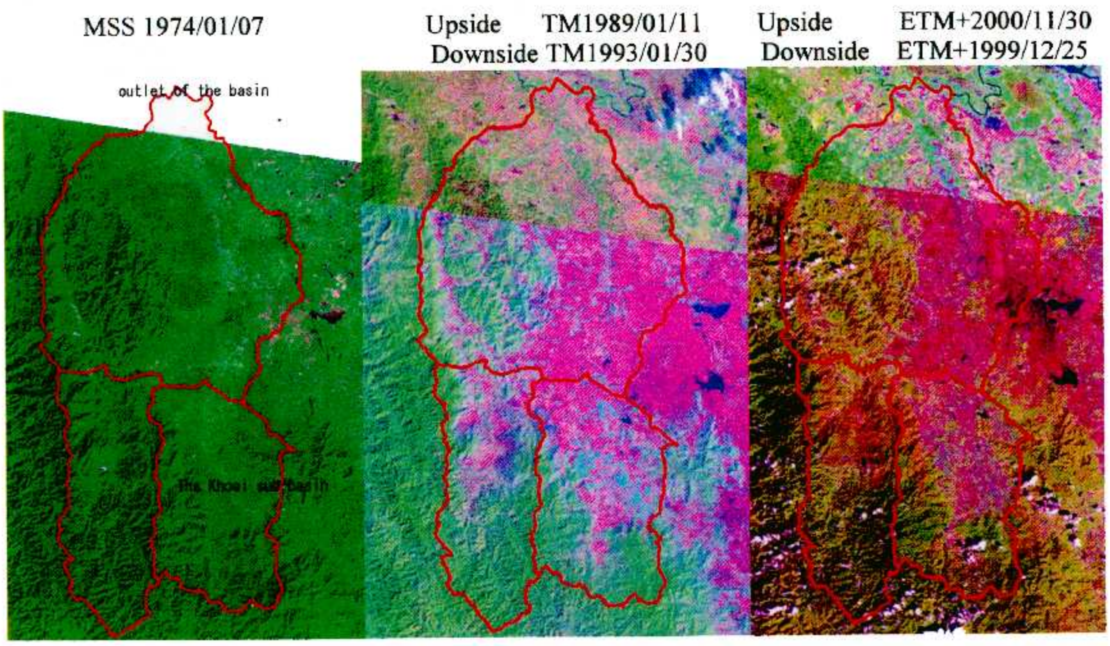

Fig. 19 Land use changes of the Lam Phachi river basin during the past three decade by the satellite images (Landsat TM1973/01/07, TM1989/01/11;1993/01/30, LandsatETM+ 1999/12/25;2000/11/09)

Green color shows forests, and reddish color shows cultivated and bare lands.

Most impacts appear to occur during the land-clearing processes and in the initial few years following cropland establishment, with much rapid storm runoff and sediment produced on disturbed areas within the cultivated land. Cultivated lands modify site hydrology by decreasing the infiltration capacity compared to forestlands. If rainfall intensity at any time during the storm exceeds the infiltration capacity, water will accumulate on the soil surface and will run down slope as a Horton overland flow. The overland flow, or surface runoff, causes sheet, rill and gully erosion. Thus, cultivated lands converted from secondary forests during the past several decades were apparently more susceptible to erosion than forestlands. This can be regarded as the primary stage for the soil erosion in Lam Phachi river basin. The conversion may be caused by the shortage of cultivated lands that resulted from the increase in rural population by settlement, and limited cultivated land resources could have accelerated the conversion during the past several decades.

According to the vegetation survey, most forests, at least the fringe of cultivated lands of the basin, were secondary forests, and also it was very difficult to find natural forests in the research target area. This suggests that before the conversion to cultivated lands the forests had been affected by various human activities such as the logging for fuel woods and for shifting cultivation by native people. However since this disturbance was within acceptable limits for watershed capacity, the productivities of the basin were sustained in those days that might continue during several hundred years.

4.2 Dynamic Cultivation Changes

Recently, forest cover in the Lam Phachi River basin has been relatively stable, however dynamic cultivation changes have occurred on the converted land related to a shift to a more cash-crop culture since the 1990s. The main cash crops in the research target area are pineapple, sugarcane and cassava. Pineapples can grow in sloping areas due to its tolerance of drought and other physiological conditions. Due to the recent high price, pineapple fields are expanding to the fringe of the forests, or the sloping area of the mountain foot. This expansion, coupled with exposed fields during tillage and early growth stages caused by the cultivation practice in which

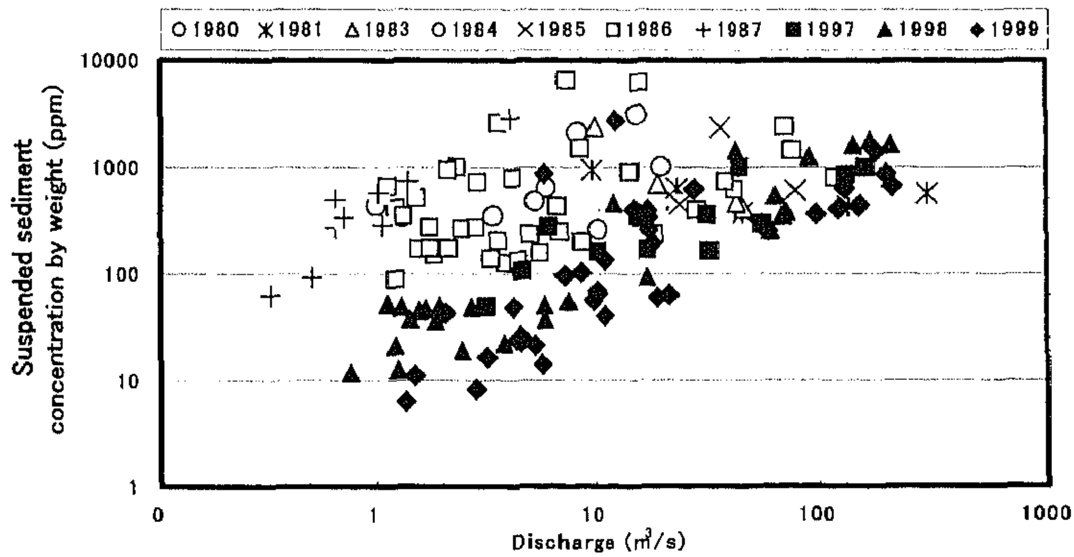

Fig. 20 Comparison of the suspended sediment concentration in the 1980s with the 1990s

that new pineapples are planted after clearing the field every three years, increased the susceptiblity to erosion more than did other crops. In the most severely eroded site, the erosion rate exceeds 100 t/ha/yr as monitored in the EP2 plot. Such severe soil erosion affects pineapple productivity by reducing the availability of water, nutrients and organic matter. This can be regarded as the secondary stage for the soil erosion.

Judging from the suspended sediment concentration data at the K17 monitoring site of Royal Irrigation Department (about 5km downstream from the confluence of the main stream with the tributary (Fig. 2)), the primary stage of soil erosion during the past few decades could supply more sediment in streams than the secondary stage during the last decade (Fig. 20). From a viewpoint of infiltration capacity, the above understanding could be supported. However, the development of irrigation ponds to cultivate land during the last decade might contribute to a lower supply of sediment to streams. Therefore, further research is required to understand the above phenomena because of complicated interrelationship of factors involved.

4.3 Vicious Cycle of Watershed Degradation

Most dynamic cultivation changes shifting from subsistence to cash crops inevitably disturb surfaces and accelera erosion. However, most watersheds have the capacity to withstand the impact of use without permanent loss of productivities so long as accelerated erosion is kept within acceptable limits. Accelerated erosion deteriorates a site to an ever greater degree unless the process is reversed (Fig. 21). The more surface runoff occurs, the more soil is removed and the less water and nutrients remain to support the plant growth that would protect it from further deterioration. A vicious cycle is initiated that reduces favorable plant growth conditions to a minimum, while erosion rates reach their maximum. Once the critical point in deterioration is exceeded, the cycle is carried to completion with the removal of the soil mantle unless people intervene to reserve the process (Satterlund and Adams, 1992).

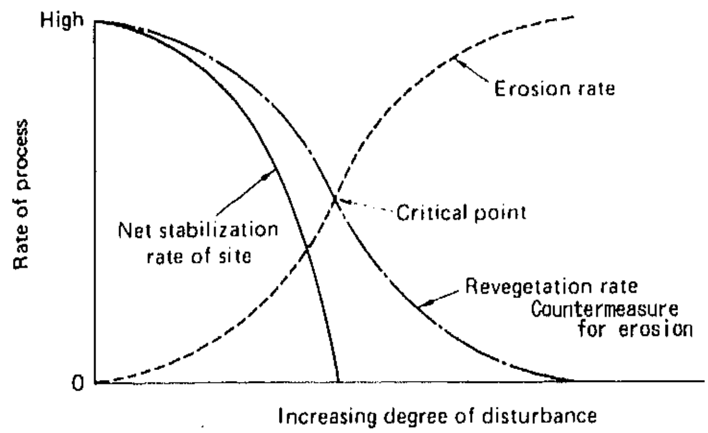

Fig. 21 Relationship of deterioration of a site by erosion to the rate of revegatation and countermeasure for soil erosion

At the critical point in deterioration, accelerated erosion becomes self-sustaining and the site cannot recover by natural processes of revegetation. To the right-hand side of the critical point, deterioration continues to completion. To the left, the site recovers its stability at an increasing rate (adapted from Satterlund and Adams, 1992).

According to the analysis using the remotely sensed data in the research target area (Ogawa, 2002), the pineapple fields area increased by approximately 20 percent during the last decade. However cultivation changes from pineapple to other crops during the this period reached approximately 70 percent, leaving the pineapple field area was only approximately 30 percent. This may suggest one reason why the dynamic change from pineapples to other crops represents the soil deterioration of pineapple fields due to soil erosion. Considering that pineapple fields around the EP1 and EP2 plots can be ranked as the highest level in soil erosion, and that the bank erosion near the IF4 site resulted from inappropriate agricultural practices coupled with the low infiltration capacity due to hardpans, the vicious cycle of watershed degradation has already begun in some cultivated areas, particularly pineapple fields of slopes in the Lam Phachi River basin. Therefore, we need protection measures against accelerated erosion, and appropriate agricultural practices to maintain the sustainable development. Cultivation along the hillslope contour and the use of agricultural hedgerows and buffer strips are useful countermeasures for soil erosion. Agroforestry practices may be a general countermeasure for reducing soil erosion. They offer a combination of both short-term economic returns to farmers (i.e., crop production) together with longer-term investments and soil and water conservation benefits (i.e., trees) (Sidle, 2002). However, research on watershed management in the context of sustainable agricultural production and environmental protection in the basin is needed in the future.

5. CONCLUSIONS

As a result of infiltration test, the forestlands have higher final infiltration rate (44-160 mm/hr) than the pineapple and cassava fields (5-39 mm/hr) though they have considerable variation in the rate depending on the soil characteristics.

According to the monitoring data that collected in 10-minute intervals at the upper region of the basin, the rainfall pattern is characterized by strong intensity and short duration. This suggests that croplands, which have the lower value in the final infiltration rate, are susceptible to soil erosion because a Horton overland flow occurs easily due to intense rainfall, but that the eroded sediment load could be not transported great distance due to the short rainfall duration.

The erosion rates of two pineapple fields in sloping area (max. slope, 11 and 18 percent) of the upper region of the basin are estimated to be 69 and 163 t/ha/yr. These values can be ranked as the highest level though they may be obtained from the pineapple fields that exhibit the most severe erosion in the research target area.

As a result of a vegetation survey, we could concluded that forests on the fringe of croplands were secondary forests and that they were immature and in the initial stage of stand development because of frequent and intensive disturbance by human activity, such as loggings and fires.

Two stages for soil erosion problems were recognized in the Lam Phachi River basin. The first stage is that forest conversion to cultivated lands was practiced in the entire basin during the past two or three decades. However, before this conversion, various human activities must have had already impacted on the basin though the productivities of the basin were sustained because the disturbance was within acceptable limits for watershed capacity.

The second stage is that dynamic cultivation changes have occurred on the converted land related to a shift to more cash-crop culture since the 1990s. According to an analysis using remotely sensed data in the target area, the area remained in the pineapple field was only approximately 30 percent. This may suggest one reason why the dynamic change from pineapples to other crops represents the soil deterioration of pineapple fields due to soil erosion. Considering that pineapple fields around the EP1 and EP2 plots can be ranked as the highest level in soil erosion, the vicious cycle of watershed degradation has already begun in some pineapple fields of slopes in the Lam Phachi River basin. Therefore, we now need protection measures against accelerated erosion, and appropriate agricultural practices in the context of sustainable agricultural production and environmental protection to maintain the sound watershed.

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REFERRENCES

FAO (Food and Agriculture Ogarnization of the United Nations) (1994): Land degradation in South Asia: Its severity, causes and effects upon the people. World Resources Report, FAO, Rome. (website: http://www.fao.org/docrep/V4360E/V4360E00.htm)

Daniel Hillel (1998): Environmental Soil Physics. Academic Press, 771pp.

Somchai Inthasothi and Kasem Chunmao (1976): Infilration capacity of soils in various types of land use at Mae Thalao watershed Chiengdao, Kog-ma Watershed Research Bulletin, Kasetsart University, **26**, 33pp.

M. J. Kirkby (1978): Hillslope Hydrology. John Wiley & Sons, Inc., 389pp.

Lorimer,C.G. and Krug,A.G. (1983): Diameter distribution in even-aged stands of shade-tolerant and midtolerant tree species. American Midland Naturalist **109**:363-345.

Hideaki Nakano (1976): Forest Hydrology. Kyoritsu Shuppan, 228pp.

H. Maita, T. Nagai, V. Vudhivanich, B. Kwanyuen, S. Ngernprascrtsri and K. Lorsirirat (1998): Analysis of Suspended Sediment Yield and Watershed Characteristics in Mae Klong River Basins. Proceedings of Workshop on Sustainable Development of Agricultural Infrastructure and Organizational Managementof Chao Phraya and Mae Klong Basins, Thailand, 38-56, Bangkok, Thailand.

H.Maita, M.Kawamoto, N. Tangyham, S. Ogawa, V. Vudhivanich and K. Lorsirirat (1999): Forest situation in the Mae Klong River Basin Analysed by Remotely Sensed Data and Relationships with Suspended Sediment Yield. Proceedings of Workshop on Sustainable Management of the Mae Klong River Basin, Thailand, 17-33, Bangkok, Thailand.

Marod,D., Kutintara,U., Yarwudhi,C., Tanaka,H. and Nakashizuka,T. (1999): Structural dynamics of a natural mixed deciduous forest in western Thailand. Journal of Vegetation Science **10**:777-786.

Shigeo Ogawa (2002): Development of agricultural land in a hilly area of the Tha Khoei River Basin. Workshop on Watershed Degradation and Restoration of the Lam Phachi River Bain, Thailand, Bangkok, November 29, 2002.

Palik,B.J. and Pregitzer,K.S. (1992): The age and height structure of red maple (Acer rubrum) populations in northern Michigan bigtooth aspen (Populus grandidentata) forests. Canadian Journal of Forest Research **22**:1449-1462.

Donald R. Satterlund and Paul W Adams (1992): Wildland Watershed Management (second edition). John Wiley & Sons, Inc., 436pp.

Roy C. Sidle (2002): An overview of Water and Related Hazards Issues in Southeast Asia. Proceedings of Tsukuba Asian Seminar on Agricultural Education 2002: Present situation on the water resources and water related disaster, and the role of Agro-environmental education (in press).