論　文

J. Jpn. Soc. Soil Phys.
土壌の物理性
No. 91, p. 25～38 (2002)

Sediment Yield from Various Land Use Practices in a Hilly Tropical Area of Lampung Region, South Sumatra, Indonesia

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Abstract

Sediments transported from various land uses and entrapped by natural vegetative filter were measured from January to November 1999 in a hilly humid tropical area of Lampung, South Sumatra, Indonesia. A very simple sediment trap made from a PVC pipe with diameter of 10.9 cm was designed for measuring the sediment yield. Five types of land uses were chosen as follows : (a) coffee garden in multistrata system followed by rain-fed agriculture and grass filter, (b) mixed-coffee garden followed by short shrub filter, (c) clean-weeded coffee garden followed by long shrub filter, (d) clean-weeded coffee garden, and (e) secondary forest followed by new forest remnant. The measurement during eleven months showed that the mixed-coffee garden produced the highest sediment yield (719.7g/m^2), and the lowest sediment yield was derived from secondary forest area (0.08g/m^2). The sediment yield from clean-weeded coffee system was around 93.4–279.7 g/m^2, and multistrata system indicated a low sediment yield (2.3 g/m^2). Although mixed-coffee garden showed a very high yield of sediment, natural vegetative strips entrapped 99.7% of the sediment. The vegetative filter zone covered with grass (1.5 m long) and short shrubs (3 m in length) could entrap 93.5% and 99.7% of sediment respectively, and the long shrub filter (12 m in length) could entrap only 52.5% of the sediment due to the concentrated flow in the longer slope. The surface cover condition of the land use system and farming activities (weeding, tillage, fertilizer application) indicated a high contribution on sediment yield than the other erosion factor.

Key words : sediment yield, coffee, vegetative filter, Indonesia

1. Introduction

Forest scattering has been a major problem in Lampung, Indonesia. The study conducted by Syam *et al.* (1997) at the upper part of Way Besai catchment, West Lampung, showed that in 1970 the forest occupied 57.4% of that areas, which became 21.4% in 1990, on the other hand the monoculture plantations (coffee tree) increased from 0% in 1970 to 41.8% in 1990. During 1998–1999, the forest scattering in West Lampung was very intensive due to the change of government which caused the weakness of law enforcement as well as the increasing of coffee price in 1999 ; the coffee price increased more than three times in 1999. Most of protected forest areas in West Lampung have been changed into coffee garden in a very short time. Although the above land use change has caused the deterioration of soil fertility as reported by Lumbanraja *et al.* (1998), the overall negative effects of this phenomenon on soil erosion process, especially off-site effect of soil erosion, is still unclear. The abundance of natural field border in this area, such as riparian, hedgerows, shrubs areas, as well litter which covered the soil surface, could affect the transfer of erosion materials (sediment). The extent of soil erosion material that will be transported is highly depended on whether the sediment meets something that can block its flow, so the position of vegetation in landscape is more important than the percentage of coverage. Although soil erosion rate from various land uses types can be easily measured using erosion plot studies, however, in a landscape scale, the existence of border strip has made the extrapolation of the results from erosion plot studies difficult.

This research emphasizes the sediment transfer across various types of land uses on coffee culture based and natural field border in West Lampung, Indonesia. In this experiment, "point measurement" is used, and can be changed into "spatial measurement" by multiplying with width and length of the areas under consideration. The objective of this research is to know the extent of sediment transfer from various land use types and natural vegetative filter.

2. Methodology

2.1 Land Use Systems

The experimental fields were located at Sumberjaya District, West Lampung, Sumatra Island, Indonesia (Fig. 1) with elevation between 700～820 m above the sea level. Five representative land use systems were chosen :

(A) Coffee garden in multistrata system followed by rain-fed agricultural field of horticultural crop with a grass filter,
(B) Mixed-coffee garden followed by short shrub filter,
(C) Clean-weeded coffee garden followed by long shrub filter,
(D) Clean-weeded coffee garden without filter,
(E) Secondary forest followed by new forest remnant

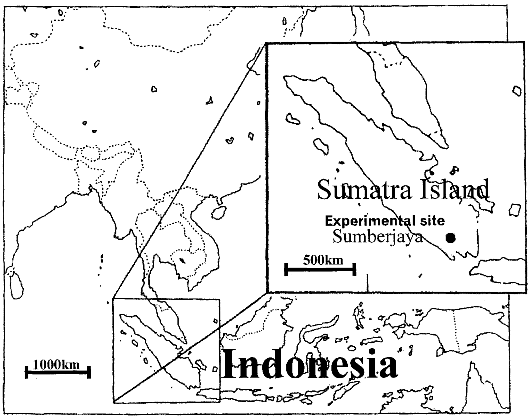

Fig. 1 Location of experimental site.

Mixed-coffee gardens consisted of various trees with different height in which coffee was the main vegetation (30–75%). Two mixed-coffee gardens were selected ; the first had nearly 30% of coffee trees with more diverse trees, and the other was dominated by coffee tree (75%) with less various trees (A1 and B1 respectively in Table 1). We designated A1 as "multistrata system" because the trees distribution is diverse, with different height than B1. The rain-fed agricultural field (A2) was located directly below the mixed-coffee garden (A1), and a narrow grass filter (A3) was situated at the edge of rain-fed agricultural filed.

Two types of coffee garden with clean-weeded ground surface were chosen. One type had a short slope of steep gradient (C1) with a long shrub filter (C2) at the edge of this slope, and the other was consisted of two long slopes (D1 and D2) without vegetative filter.

The forest area was a secondary forest with various types of trees (E1). Below this forest area, there was a new cleared land of forest with ground surface covered by cutting trees (E2). We designated E2 as "new forest remnant"

The annual rainfall was around 2600 mm/year ; the rainy season is usually from November to May of the following year. The rainy season was followed by weak dry season because usually rainfall still occurs more than 100 mm every month. The daily average temperature was 22℃ and relative humidity was 87.2%. The period of experiment lasted from January 1999 to November 1999.

2.2 Sediment Trap Equipment

The designed simple sediment trap (Fig. 2) consisted of four components as follows :

(a) Sediment collector made of PVC-tube with 10.9 cm diameter.
(b) Plastic funnel inside the L-tube.
(c) PVC tube with diameter 7.5 cm ; the tube was drilled with nine holes at the wall side, and one hole was connected to small plastic bucket ; a filter paper was placed at the bottom of tube and supported by a cloth.
(d) Small plastic bucket, consisted of filter paper and cloth

Samples of sediment were collected at least once in a week ; the frequency of sampling depended on the amount of the rainfall. The sample was collected by changing the filter paper with a new one (known weight) and packed into plastic bag. The sediment was taken to laboratory, dried and weighed. When the samples were too large, a sub sample was taken.

Total sediment was calculated as follows :

$$S_a = S_e + 9 \times S_b \quad (1)$$

S_e : dry weight of sediment in the PVC tube (g)

S_b : dry weight of sediment in small plastic bucket (g)

S_a : total sediment weight (g)

2.3 Location of Sediment Traps

Three to five sediment traps were set up respectively at the lower boundaries of the land use as follows :

(A) –Multistrata systems with coffee trees and surface mulch (A1)
–Rain-fed agricultural field in the valleys grown with horticultural crops (A2)
–Grass filter zone (A3)
(B) –Mixed-coffee garden with short slope (B1)
–Short shrub strip (B2)
(C) –Clean-weeded coffee garden before shrub strip (C1)
–Long shrub strip (C2)
(D) –Clean-weeded coffee garden at upper part of slope (D1)
–Clean-weeded coffee garden at lower part of slope (D2)
(E) –Secondary forest areas (E1)
–New forest remnant (E2)

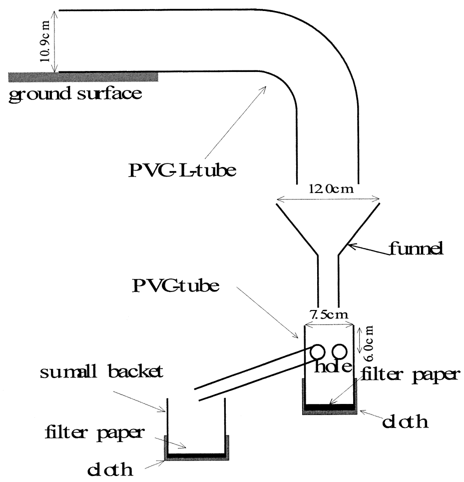

Fig. 2 Structure of Sediment Trap.

The description of each site is tabulated in Table 1 and those photos are shown in Fig. 3.

2.4 Analysis

The sediment yield was calculated by dividing the sediment caught in sediment trap with areas, i.e. the slope length times the width of the sediment trap as follows :

$$S_y = S_a / (L \times W) \quad (2)$$

S_y : sediment yield per unit area (g/m^2)

S_a : total sediment weight (g)

L : slope length (m)

W : width of sediment trap (=0.109 m)

Because no exact boundaries were made, the accuracy of soil erosion (sediment) entrapped by the sediment trap is more or less influenced

Table 1 Description of each representative land use

Code	Land Use	Name	Vegetation Number	Vegetation Height (m)	Vegetation Distance (m)	Slope (%)	Length (m)	Note
A1	Multi-Strata	coffee bananas jack fruit guava durian	main 10 2 3 1	2 2 4 4 5	3×2.5	37	9–10.5	surface covered by litter (25%) below this land use is rain-fed agriculture
A2	Rain-fed agriculture	beans chilli	10 furrows			45	15–22.5	Jan.-March (beans) Apr.-June (cowpea/chili) Jul.-Dec. (fallow) A2 was below A1
A3	Grass (filter)	small grass		0.05–0.1	dense	5–9	1.5	A3 was below A2 Sawah/paddy field is below this filter
B1	Coffee (mixed)	coffee bananas trees	main 5 3	2 2 6	3×2.5	25	9.5	Clean-weeded. coffee tree >50% with other trees alternate between the coffee tree
B2	Shrubs (filter)	weeds (woody weeds, ferns)			dense	82	3	B2 was below B1. Sawah is below this filter. The weeds were dominated by *Clibadia surinamenses.*
C1 C2	Coffee Shrubs	coffee weeds (woody weeds, ferns)		1.65	2×2 dense	65 90	18.5 12	Clean-weeded coffee garden. C2 follows C1. Creek is below this filter. *Clibadia* sp. is dominated.
D1	Coffee	coffee	main	1.65	2×2	42	33.5	Clean-weeded coffee field.
D2	Coffee	coffee	main	1.65	2×2	42	13.5	Clean-weeded coffee field. D2 was below D1. Intermittent creek is below this field
E1	Forest	mixed (trees,bamboo, rattan,etc.)			dense	90	>300 to the top	Below E1 was E2
E2	Forest (open)	surface covered with falling trees				70	40	New at the end of January, 1999.

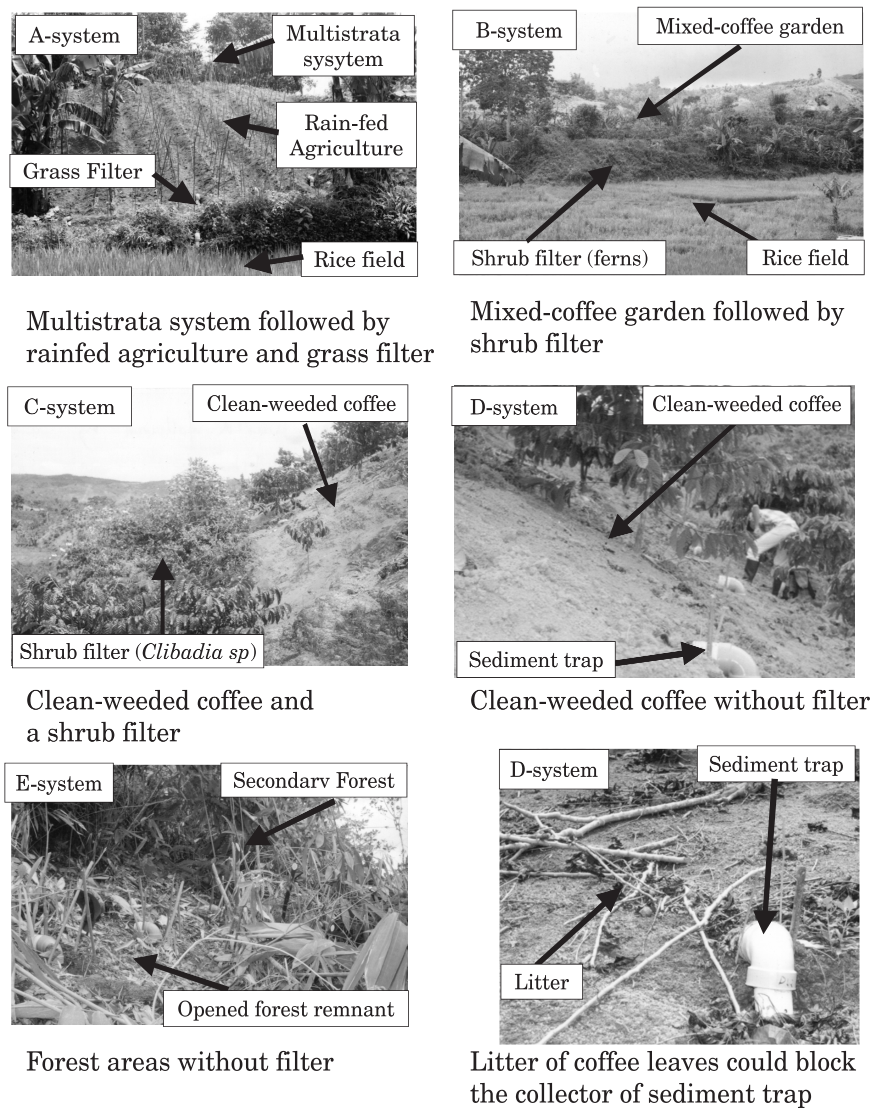

Fig. 3 Land use types.

by the place of location of sediment trap. Five sediment traps were set up randomly in each land use, one or two in rill and runoff pathways. That is why the data between replications is varied, with high standard deviation. It was assumed that the sediment entrapped by this equipment was representative of the soil loss from the area with the width of sediment collector and slope length. In these methods, "point measurement" can be changed into "spatial measurement" by multiplying with the areas under consideration.

Since there were two or three types of land use in one land use system, the sediment yield of the second or third land use was calculated using the total length of upper slopes. The following example shows the calculation of sediment yield for A-land use system that consisted of multistrata (MS), rain-fed agriculture (RA) and grass filter (GF).

Figure 4 shows that the sediment yields which deposited in grass filter (Sa_{GF}) was the

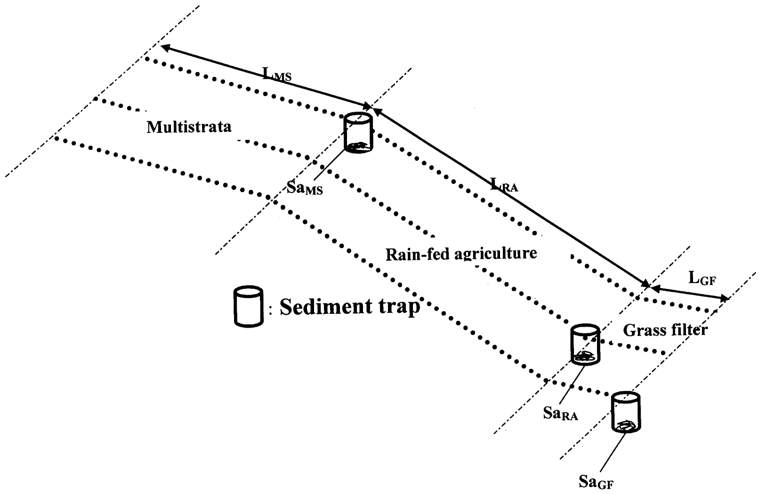

Fig. 4 Multistrata system followed by rain-fed agriculture and grass filter.

result of soil loss from the whole areas (multistrata, rain-fed agriculture, and grass filter). The calculation of the sediment yield in each land use is as follows :

$$S_{yMS} = S_{aMS} / (L_{MS} \times W) \quad (3)$$

$$S_{yMS\text{-}RA} = S_{aRA} / [(L_{MS} + L_{RA}) \times W] \quad (4)$$

$$S_{yMS\text{-}RA\text{-}GF} = S_{aGF} / ([(L_{MS} + L_{RA} + L_{GF}) \times W] \quad (5)$$

Where :

S_{yMS} : sediment yield from multistrata system (g/m^2)

S_{aMS} : sediment caught by sediment trap at multistrata system (g)

L_{MS} : slope length of mulstistrata system (m)

W : width of sediment trap (=0.109 m)

$S_{yMS\text{-}RA}$: sediment yield from multistrata and rain-fed agricultural system (g/m^2)

$S_{a\,RA}$: sediment caught by sediment trap at rain-fed agriculture (g)

L_{RA} : slope length of rain-fed agricultural system (m)

$S_{yMS\text{-}RA\text{-}GF}$: sediment yield from the whole land use system (multistrata+rain-fed agricultural system+grass filter) (g/m^2)

S_{aGF} : sediment caught by sediment trap at grass filter (g)

L_{GF} : slope length grass filter (m)

To test the effectiveness of the filter, a simple comparison was made between the amounts of the sediment entering the filter (S_e) and the sediment leaving the filter (S_o) as follows :

$$\text{Filter effectiveness} = [(S_e - S_o)/S_e] \times 100 \ (\%) \quad (6)$$

S_e : sediment yield entering from upper slope to the filter (g/m^2)

S_o : sediment yield leaving the filter for the next land use system (g/m^2)

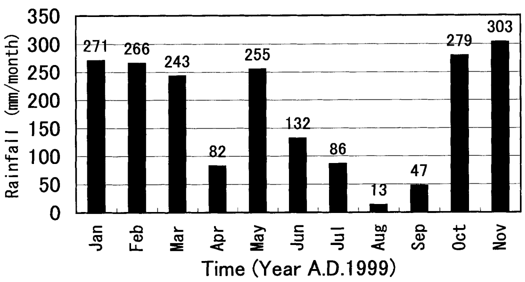

Fig. 5 Distribution of rainfall during the experimental period.

3. Results and Discussion

3.1 Rainfall

The amount of rainfall during the experiments was 1975.5 mm. The distribution of rainfall is shown in Fig. 5 and is not well distributed. A very low rainfall was found in April although it was rainy season. A dry season developed from July to September. The

Table 2 Composition of soil fraction at the experiment site (0–20 cm)*

No	Land use	Clay %	Silt %	Sand %	Texture Class
1	Multistrata system	55.4	12.5	32.1	Clay
2	Rainfed agriculture (horticultural crop)	48.6	18.4	33.0	Clay
3	Mixed coffee garden	58.2	15.4	26.4	Clay
4	Clean-weeded coffee with filter	48.5	20.1	31.4	Clay
5	Clean-weeded coffee-upper slope	60.3	14.4	25.3	Clay
6	Clean-weeded coffee-lower slope	50.2	18.4	33.4	Clay
7	Forest (Mount Rigis)	38.0	24.0	38.0	Clay loam

*) analyzed using hydrometer method

Table 3 Selected soil physical properties

No	Land use	Bulk Density (g/cm^3)	Particle density (g/cm^3)	Organic-C (g/kg)	Dispersion ratio*)
1	Multistrata	0.97	2.48	43.7	67
2	Rainfed agriculture	1.11	2.51	21.9	89
3	Mixed coffee garden	0.98	2.46	30.5	78
4	Clean weeded coffee-long shrub	1.03	2.46	27.8	85
5	Clean weeded coffee-upper slope	1.02	2.48	28.6	82
6	Clean weeded coffee-lower slope	0.98	2.46	35.6	86
7	Forest	0.96	2.43	55.4	60

*) Dispersion ratio (%)=(clay+silt) undispersed/(clay+silt) dipersed×100

amount of rainfall in May and June (starting dry season) was 255 and 132 mm respectively, a little higher than that of March and April (243 and 82 mm respectively) still in rainy season.

The rainfall erosivity index (R) in this area could be approached by using equation proposed by Utomo and Supriyadi (1989) as follows :

$$R = -8.79 + 7.01\,CHb \quad (7)$$

R : monthly rain erosivity ($t \cdot m^2/ha/h$), CHb : Monthly rainfall (cm)

Using this equation, the total erosivity index during eleven months of experiment was estimated at 1289($t \cdot m^2/ha/h$).

3.2 Soil Properties

Based on the soil taxonomy by Soil Survey Staff (1998), the soil was classified as Dystrudepts, dominated by clay fraction whose ranges are from 38.0 to 60.3% (Table 2).

Due to the fact that the soil is still relatively young (Inceptisols), the bulk density and particle density are relatively low, and the dispersion ratio is very high although the organic carbon is high enough (Table 3). The research area is located in the mountainous areas which elevation between 780–850 m, so the low temperature is enough to maintain the high organic matter in this area. The soil permeability is difficult to measure because the soil has swell and shrink properties, so many cracks are always found in the soil profile. From this fact, it could be estimated that the permeability of the soil is very high or the internal drainage is very excessive. The strong red color of the soil profile supports this fact. As consequence, the leaching process which carried soil particles from upper layer is very intensive, and although the dispersion ratio is very high and the soil could be classified as erodible, the soil erosion by runoff water could be low.

3.3 Sediment Yield from each Land Use system

(1) Sediment yield from multistrata system followed by rain-fed agricultural field with horticultural crops and grass filter (A-system)

The sediment yield measured at lower boundary of multistrata system, rain-fed agricultural field with horticultural crops and grass filter are shown in Fig. 6.

As shown in Fig. 6, the sediment yield from multistrata system was very low. Total amount of sediment yield from multistrata system was only 2.3 g/m^2 in 11-months measurement, compared to the sediments caught by the traps of rain-fed agricultural field and grass filter which were 423.2 g/m^2 and 26.5 g/m^2 respectively. The sediment yield caught at rain-fed agriculture increased 184 times than in multistrata system, however, most of this sediment was deposited in grass filter. This experiment showed that although the grass filter was very short (2 m length), it could entrap the sediments up to 93% (in Table 4) of inflow, and only small portion of sediment was transferred to the next system (rice field).

It is interesting to note that the sediment yield during the dry season was still very high. As shown in Fig. 6, the sediment yield in May, June, and July were higher than that of the rainy season (January-April). Even for grass filter, the major contribution of sediment yield occurred on July (about 51% of all sedimentation for 11 months), although the monthly rainfall was low.

Tillage activity and time lag of sediment transportation may induce the above results. During heavy rainfall event on rainy season, the weeds and beans covered the portion of ground surface at rain-fed agricultural field, so this vegetation would reduce soil erosion process. Following the beans harvest in April, the farmer began preparing the land for growing chili and cowpea, and this land preparation would have strongly affected the soil condition and surface cover ; soil surface was clear and soil structure was loose. This condition would stimulate soil erosion process. Time lag of sediment transportation will also influence sediment transfer, especially in the filter area. The accumulation of sediment yield, which was produced during rainy season, was transported in the following dry season.

(2) Sediment yield from mixed-coffee garden followed by shrubs filter (B-system)

As shown in Fig. 7, the sediment yield from mixed-coffee garden and entrapped by shrubs

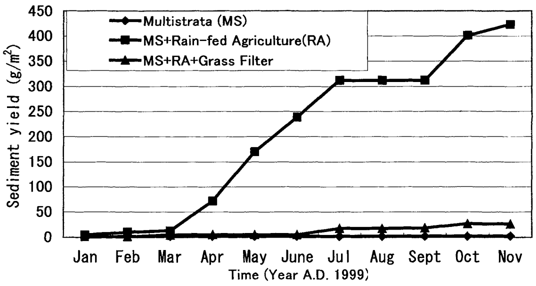

Fig. 6 Accumulation of sediment yield from multistrata system followed by rain-fed agriculture and grass filter (A-system).

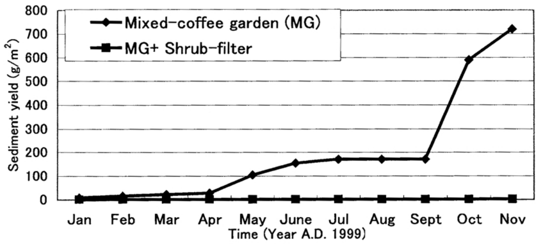

Fig. 7 Accumulation of sediment yield from mixed-coffee garden followed by short shrub filter (B-system).

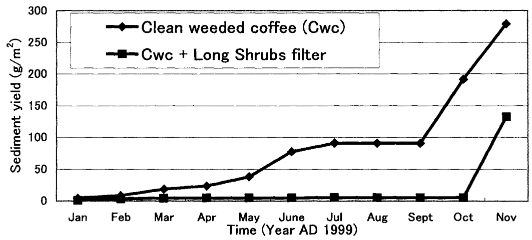

Fig. 8 Accumulation of sediment yield form clean-weeded coffee before entering long shrub filter (C-system).

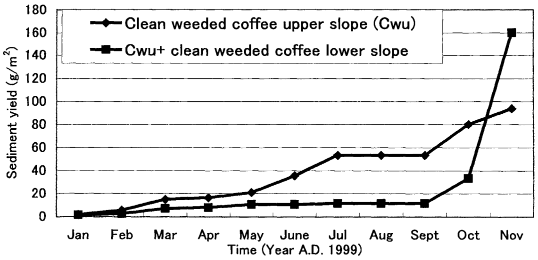

Fig. 9 Accumulation of sediment yield from clean-weeded coffee without filter (D-system).

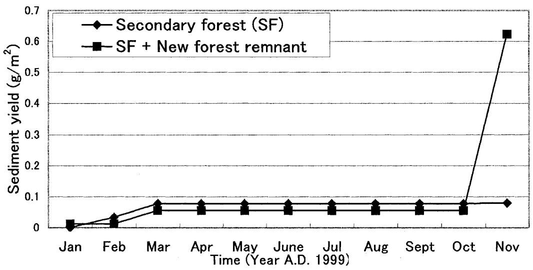

Fig. 10 Accumulation of sediment yield from secondary forest without filter (E-system).

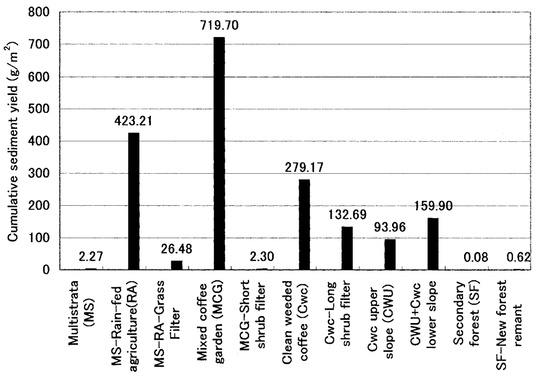

Fig. 11 Cumulative sediment yield from various land use system.

filter were 719.7 g/m^2 and 2.3 g/m^2 respectively. The vegetative filter was dominated by woody weed species, identified as *Clibadia surinamenses*. Ferns comprised the other species. Although the shrub filter was very steep (slope gradient was 82%) and short (only 3 m), it was very effective to entrap the sediment from the above system. Most sediment from mixed-coffee garden was entrapped in the filter (99.7% in Table 4), and only small portion (0.3%) passed and transferred to the next land use (rice field).

The biggest contribution of sediment from the mixed-coffee garden occurred in October. Due to abundance of water during rainy season, weeds under the coffee tree grew very fast, so farmer began clearing weeds at the end of rainy season (May or June). Farmers cut the weeds using hoe. The hoe is struck into the soil surface, so the weed roots will be truncated from the soil. This activity would also be done at the beginning of rainy season (early October), due to some reasons such as weeding activity and fertilizer application. Those tillage activities could break and loose the soil surface, and enhance soil erosion due to detachment process by farmer hoe.

(3) Sediment yield from clean-weeded coffee followed by shrub filter (C-system)

Sediment yield from clean-weeded coffee and entrapped by shrubs filter were 279.2 g/m^2 and 132.69 g/m^2 respectively as shown in Fig. 8. The biggest contribution of sediment yield from the filter occurred on October and November 1999, about 67% of total sediment yield for 11-months observation. It is fairly difficult to decide which process was responsible for high sediment transfer. Although field evaluation showed that a rill has developed at the upper part of this sediment trap, an evidence of sediment accumulation indicated that a small landslide might also be responsible.

The other possibility is the side effect of weeding activity by the farmer. As commented above, the farmer usually has a lot of activities at the end of rainy season and at the beginning of rainy season, including weeding, fertilizer application, and soil tillage. As shown in Fig. 8, the results of these activities were shown in the form of sediment yield, which still occurred in the coffee garden during the dry season (July). During the next rainy season, the sediment will be transferred to the lower slope.

(4) Sediment yield from clean-weeded coffee (D-system)

The sediment yield from upper and lower slope of clean-weeded coffee garden without any conservation measure or vegetative filter was 93.6 g/m^2 and 159.9 g/m^2 respectively as shown in Fig. 9. Total sediment yield at lower slope was greater than upper slope which suggests that sediment from upper slope made a higher contribution to the sediment at the lower slope. Also of note is the finding that before October, the sediment yield of upper slope was always greater than that caught in the trap of lower slope. As shown in Fig. 9, major portion of sediment yield (43.2%) caught in clean-weeded coffee at lower slope occurred on November. Instead of farmer activities that have been discussed above, the litter of coffee leaves also affected the sediment transfer before November. As shown in Fig. 3, the litter had blocked the sediment trap, thus reducing the transportation of sediment. After the farmer removed litter because it was afraid that the litters were used as insect nest, the sediment yield increased remarkably. As shown in Fig. 9, there is increasing sediment yield in November 1999, from 33 g/m^2 in October to 159.9 g/m^2 in November.

(5) Sediment yield from secondary forest and new forest remnant (E-system)

Total sediment yield from forest areas and entrapped by new forest remnant were 0.08 g/m^2 and 0.62 g/m^2 respectively as shown in Fig. 10. Although the slope is very steep (90%), sediment yield from secondary forest was very low. The reduction of rainfall energy by canopy of trees and the dense of vegetation at ground surface that served as barrier were responsible of low sediment yield. However, about 6.9 times of sediment yield occurred when forest was opened, but the value was still lower than the other land use system measured in this experiment. As shown in Fig. 3, the surface condition of new forest remnant was still fully covered by litter,wood debris as well as falling tress, which are still very effective in preventing sediment transfer.

(6) Total sediment yield from various land uses (F-system)

Total sediment yield from various land uses during 11 months measurement are shown in Fig. 11. The amount of sediment yield entrapped by each land use system was as follows : the mixed-coffee garden (719.7 g/m^2) ; multistrata system followed by rain-fed agri culture (423.2 g/m^2) ; clean-weeded coffee garden (279.7 g/m^2) ; clean-weeded coffee garden at upper and lower slope (159.9 g/m^2) ; clean-weeded coffee garden and long shrub filter system (132.7 g / m^2) ; clean-weeded coffee garden at upper slope (94.0 g/m^2). On the other hand, the sediment yield from the forest areas was almost zero (0.08 g/m^2) and which was entrapped by new remnant system was 0.6 g/m^2. The multistrata system also produced a very low sediment yield (2.3 g/m^2) and sediment entrapped by grass filter (which composed of multistrata and agriculture system above) was 26.5 g/m^2.

If the above unit changes into t/ha or mm (assumed soil bulk density 1 g/cm^3), the values of sediment yield range from 0.0008 to 7.2 t/ha or 0.00008 to 0.7 mm. These values are lower than sedimentation in some critical watersheds in Indonesia reported by Utomo (1989). For example, sediment yields in Way Sekampung watershed, Cilutung, and Brantas were 8.7, 9.0, and 0.25 mm/year respectively.

In the current study, three coffee garden systems produced different amounts of sediment, i.e. coffee in multistrata indicated 0.023 t/ha, clean-weeded coffee indicated 2.8 t/ha and 1.6 t/ha (at lower slope) and mixed-coffee garden indicated 7.2 t/ha. The highest value of sediment yield in mixed-coffee garden was due to the more intensive farmer activity in this land use compared to the other coffee land use system.

The high value of sediment yield in mixed-coffee garden will not reach the stream since

Table 4 Effectiveness of various natural vegetative strips in the study area (0–40 cm)

No	Description of filter	Sediment entrapped (%)
1	**Grass filter** : consists of small grass and sparse bananas ; located at bottom of the slope (5–9%) ; 1–3 m length. The sediment source is rain-fed agriculture with horticultural crops.	93.7
2	**Shrubs filter** : consists of woody species (*Clibadia sp.* and various ferns) ; located near at foot slope with length 3 m and gradient of 82%. The sediment source is mixed-coffee garden.	99.7
3	**Shrubs filter** : consists of woody species (*Clibadia sp.* and various ferns are dominant) and small grass at bottom of this filter ; located at mid-slope with 12 m in length and gradient 90%. The sediment source is clean-weeded coffee.	52.5

99.7% will be trapped by shrubs filter, and even if it passed through the filter, the sediment will be deposited in the next land use system, paddy field. This situation demonstrated the importance of natural vegetative filter as well as the arrangement or structure of land use system in a landscape for soil conservation in coffee areas in Lampung, Indonesia. This finding was confirmed by the experiment of Sinukaban *et al.* (2000). Using a catchment's approach, Sinukaban *et al.* (2000) had shown that the water flow from that area relatively remained constants although sharp land use changes occurred in this area from forest to coffee plantation during the years 1970 to 1990.

In case of clean-weeded coffee garden without filter (at lower slope), the sediment will directly flow into the creek and carried by running water. So from the viewpoint of soil erosion process, the clean-weeded coffee at lower slope has contributed the highest sediment yield. On the other hand, the multistrata system produced a very low sediment yield, indicating this is an optimal system to protect soil against water erosion. Multistrata system is very effective to reduce the rainfall energy by intercepting raindrops before they strike to the soil. Litter leaves that covered ground surface also reduced surface runoff.

It appears that surface cover condition of land use system provided a high contribution on sediment yield other than the soil erosion factors. Although forest area has steeper slope (90%) than clean-weeded coffee garden (25〜65%), they offer better performance in modifying the erosion process. The effect of farming activities (weeding, tillage) showed a high contribution in promoting sediment yield. These activities had affected the soil surface condition, such as vegetation coverage and soil condition. If erosive agent could define soil erosion process as detachment and transportation of soil particles, then the soil detachment process has been done by the farmer activities.

(7) Filter effectiveness

Filter in general sense can include a range of landscapes elements: depression, cut-off drains, ditches, embankment, vegetated strips, hedgerows, and riparian vegetation (van Noordwijk *et al.,* 1998). We recognized one natural vegetative strip which is abundant in the study area, i.e. shrubs filter which consisted of various weed species, mainly *Clibadia surinamense* and various type of ferns. *Clibadia* sp. is a woody

Table 5 Average of standard deviation (SD) and coefficient of variation (CV) among the replications

No	Land use	Mean* (g)	Standard deviation** (g)	Coefficient of Variation (%)
1	Multistrata	2.5	1.87	75
2	Rain-fed agriculture	1408.1	326.9	23
3	Grass filter	93.9	96.8	103
4	Mixed-coffee garden	755.1	757.3	100
5	Shrub filter	3.3	3.2	98
6	Clean-weeded coffee	553.8	444.5	80
7	Long shrub filter	431	909.3	211
8	Clean-weeded coffee upper slope	343.1	198.2	58
9	Clean-weeded coffee lower slope	819.2	576.8	70
10	Secondary forest	2.2	2.5	113
11	New forest remnant	23.1	42.5	184

*) mean monthly during total experiment time (11 months)
**) among replications for 11 months measurement

species that could reach 1.5 m in height. The description of each filter strips is presented in Table 4. All the vegetative filter strips fully covered the ground surface. However, there are several differences among the canopy types of each filter. Grass filter could cover the entire soil surface, however due to short height of the grass, runoff water and sediment could still flow above the grass. Shrubs filter which was mainly consisted of "woody species", have leaves and branches which could cover the entire ground surface cover, so it will be effective in protecting against raindrop. However, under the canopy of shrubs, the coverage on the ground surface is not so dense, and runoff water and sediment still could run between the "individual species".

The effectiveness of natural vegetative filter in entrapping sediment was as follows : grass filter 93.5%, short shrubs filter 99.7% and long shrubs filter 52.5%.

Instead of vegetation type inside the filter, the effectiveness of natural filter strip in entrapping or transferring sediment also depends on slope length. This study showed that short filter cover with small grass or shrubs was very effective to entrap the sediment than a very long one. Runoff will have a chance to accumulate in the longer slope, and a rill will be created if there is a concentrated flow.

(8) Variability

The sediment trap was very simple and very easy to maintain. The data could be collected on rainfall event basis or daily basis. However, because the measurement has been done in the natural condition, some weakness related to statistical aspect is appeared. The variability among the replications could be expressed by calculating the standard deviation (SD) and the coefficient of variation (CV). The SD and CV during the experimental period are shown in Table 5. The CV was very high, between 23% until 211%.

The lowest variability was found in rain-fed agriculture with horticultural crop (23%) due to the fact that the farmer have cultivated the soil as uniform as possible for growing a high value crops that need the same distance and good soil management. A very high coefficient of variation was found in long shrubs filter (211%), new forest remnant (184%), and secondary forest (113%). At least there are three reasons why high coefficient of variation among the replications appeared : (a) the development of a concentrated flow of runoff (or rill erosion) above a sediment trap, (b) the farmer activity for cultivating the soil, and (c) and the existence of litter at the ground surface, as shown in Fig. 3.

4. Conclusion

The existence of natural vegetative strips was very effective in entrapping sediment transfer, and the effectiveness ranged between 52.2～99.7%. Although mixed-coffee garden indicated the highest yield of sediment (719.7 g/m^2), the sediment that left the whole mixed coffee garden system was very low (2.3 g/m^2) due to filter entrapping. The lowest sediment yield was found in secondary forest (0.08 g/m^2), and the highest values of sediment yield which discharged into the river was found in clean-weeded coffee garden as much as 159.9 g/m^2. Coffee in multistrata system also produced a very low sediment yield (2.3 g/m^2). The sediment yield values in this area were still lower than the other place in Indonesia. The soil covered condition of land use system and farmer activities (weeding, tillage, and fertilizer application) gave a high contribution on sediment transfer other than soil erosion factors such as slope gradient and rainfall.

Since the measurement was made under natural condition, the coefficient of variation among the replications was very high. The minimum value of coefficient of variation was found on rain-fed agriculture (23%) and the maximum value was found on long shrubs filter (211%).

Acknowledgments

We wish to convey our gratitude to the International Center for Research in Agroforestry (ICRAF) South East Asia, especially to ICRAF staff Dr. Meine van Noordwijk and Dr. Thomas P. Tomich, and the Asian Development Bank (RETA 5711) for financial support.

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インドネシア・スマトラ島ランポンの熱帯丘陵地における異なる土地利用からの土壌侵食

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要　　旨

インドネシア・スマトラ島ランポンの熱帯丘陵地において，種々の土地利用と植生帯からの侵食土量を測定した。自然状態で土壌侵食量を測定するためにPVCパイプで作成した簡易な装置を考案し，次の5タイプの土地利用システムを対象に設置した。すなわち，(a) 多階層型混作システムのコーヒー園，天水型畑地，草生帯，(b) 混作型コーヒー園と短斜面の低木植生帯，(c) 除草したコーヒー園と長斜面の低木植生帯，(d) 除草した斜面長の異なるコーヒー園，(e) 二次林と伐採直後の二次林，である。11ケ月間の観測から，混作型コーヒー園の土壌侵食量が最も大きく（719.7 g/m^2），二次林からの侵食量が最も少ない（0.08 g/m^2）。さらに，除草したコーヒー園からの土壌侵食量が93.4〜279.7 g/m^{2}であるのに対して，多階層型混作システムのコーヒー園からの土壌侵食量が小さい（2.3 g/m^2）。コーヒー園の下流側に自然植生帯があれば，それによってコーヒー園からの侵食土壌の大部分を捕捉することができた。1.5 mの斜面長を持つ草生帯や3 mの斜面長を持つ低木植生帯は，それぞれ上流からの侵食土壌の93.5%，99.7%を捕捉することができた。一方，12 mの長い斜面長を持つ低木植生帯は，斜面内で流出水が集中するために侵食土壌の52.5%しか捕捉することができなかった。圃場面の植生状態に加えて，耕作者による農作業（除草，耕起，施肥）が土壌侵食量に大きな影響を与えた。

キーワード：土壌侵食量，コーヒー，植生帯，インドネシア

受稿年月日：2001年10月25日
受理年月日：2002年5月13日