Soil erosion from catchment and plot scales under coffee tree based crop in humid tropical climate of Lampung, Indonesia

by Ananto Aji

Soil erosion from catchment and plot scales under coffee tree based crop in humid tropical climate of Lampung, Indonesia

Afandi[1], Didin WIHARSO[1], Ananto AJI[1], Masateru SENGE[2] and Kengo ITO[2]

Abstract: Problems have been widely encountered when trying to scale erosion results from plot to catchment level. Due to the complex hydrological response in catchment, the soil erosion from plot level does not always correlate with erosion measured at the catchment scale. An experiment was conducted to measure the soil erosion at both plot and catchment levels under coffee tree based crop in Lampung, Indonesia. Runoff and sediment were measured at the catchment of 10.2 ha, while seven erosion plots of 75 m^2 were constructed inside the catchment. The erosion plots were designed as follows; (a) bare soil (control), (b) natural weeds (NW), (c) clean weeded coffee, (d) coffee with *Paspalumcon jugatum* (PC) in spot weeding, (e) coffee with PC in strip along the contour line, (f) coffee with NW in spot weeding, and (g) coffee with NW in strips. After one and a half years measurement, the rate of soil loss ranged from 0.12 t ha^{-1} (natural weed plot) to 0.87 t ha^{-1} (bare soil plot). On the other hand, the sediment yield from the catchment was 6.7 t ha^{-1} for 8-months measurement during the rainy season. These experiments indicate that, the sediment yield from the catchment level is more than ten times that of soil loss from plot scale. This is supposed, to be responsible for the gully erosion, collapse and soil erosion from paddy field which occurred in the catchment. This result showed that the soil conservation strategy which is now mainly focused on only cropped areas must be revised, and the other sources of sediment yield must be taken care of to curtail downstream soil erosion.

Key Words : catchment, coffee, Indonesia, sediment yield, soil erosion

1. Introduction

In Indonesia, erosion research is mainly carried out at the plot scale level and the result is used to recommend soil conservation program at wider levels such as catchment level. As a matter of concern, the on site soil erosion is of no problem, however the problem will arise when soil erosion on plot level is scaling up to that of catchment level. The soil erosion in catchment scale could be lower or higher than soil erosion in plot scale. For example, Afandi et al. (2002) and Dariah et al. (2004) reported that at plot level, the average soil loss from clean-weeded coffee at Sumber Jaya, Lampung, Indonesia, was very small. However, in catchment scale, the Ministry of Forestry and Estate (1999) determined that the Tulangbawang watershed, in which Sumber Jaya is included, was marginal catchment due to high sedimentation, and in 2009, it was categorized as poor catchment (Ministry of Forestry, Republic of Indonesia, 2009a). As such, the measurement of soil erosion in both scales has become important in integrating the strategy of soil and water conservation.

Many case studies have reported both positive and negative non-linear relationship between basin area and sediment yield. Braud et al. (2001) showed the difficulty in relating runoff volume and sediment yield to simple descriptors of the catchment such as the average slope and/or the average vegetation cover. Ceballos and Schnabel (1998) emphasized that the valley bottom played an important role in sediment yield, as also shown by Steegen et al. (2001). Using ^{137}Cs tracing technique, Li et al. (2009) also found that paddy field and caotu (a kind of cultivated land located at the foot of hills) were depositional areas.

Land use change from forest to the other agricultural purposes is often seen as the main factor to increase in soil erosion and sediment yield. However, there has not been any significant change in discharge of the main river at the catchment (Sihite, 2001) although it is reported that, there has been a sharp change of land use at Sumber Jaya areas, Lampung, Indonesia, where in 1970 the forest area occupied 58 % of that area, which was reduced to 21 % in 1990 (Syam et al., 1997), and 12 % in 2000 (Verbist et al., 2005), while the coffee areas increase 10 fold from 7 % of the total land area in 1970 to 70 % in 2000 (Verbist et al., 2005). Afandi et al. (2002) and Dariah et al. (2004) also reported that the average soil loss from clean-weeded coffee was also very small. However, Rijsdijk et al.(2007a, 2007b) reported that the sediment yield from rural roads, trails, settlements, gullies, riparian mass wasting and bank erosion, in Kali Konto catchment, Indonesia, contributed a significant proportion of the total soil erosion.

[1]Faculty of Agriculture, The University of Lampung, Jl. Prof. Dr. Sumantri Brojonegoro No. 1, Lampung, 35145, Indonesia.
[2]Faculty of Applied Biological Science, Gifu University, 1-1 Yanagido, Gifu 501-1193, Japan. Corresponding author: 千家正照, 岐阜大学応用生物科学部
2010 年 2 月 26 日受稿　2010 年 6 月 11 日受理
土壌の物理性 115 号, 15–23 (2010)

Table 1 Soil morphology and physical properties in the study area.

Soil depth (cm)	Horizon	Soil structure*	Soil texture** (g g^{-1})			Crack	Roots
			sand	silt	clay		
0 – 6	A	sab	0.160	0.272	0.568	crack	f-many, md-common, c-few
6 – 28	AB	sab	0.127	0.292	0.581	crack	f-many, md-common, c-few
28 – 72	Bw1	ab	0.119	0.308	0.573	crack	f-common, md-few
72 – 104	Bw2	ab	0.296	0.234	0.470	crack	f-few
104 – 153	Bw3	ab	0.376	0.264	0.360	-	f-few

* Soil structure: ab (angular blocky), sab (sub angular blocky); Roots: f (fine root), md (moderate root), c (coarse root) .
** Soil texture is classified by USDA method.

Table 2 Land use type and soil texture (0–20 cm depth) in the catchment.

No.	Land use	Area (ha)	Area (%)	Soil texture* (g g^{-1})		
				sand	silt	clay
1	Coffee with tree crops	4.55	44.6	0.232	0.127	0.641
2	Coffe in monoculture	1.13	11.1	0.152	0.114	0.734
3	Coffee with various cash crop	0.75	7.4	0.266	0.121	0.613
4	Coffee with vegetable crop	1.40	13.7	0.180	0.210	0.610
5	Chilli	0.11	1.1	0.198	0.157	0.645
6	Rice field	0.10	1.0	0.167	0.197	0.636
7	Shrub	2.15	21.1	0.160	0.090	0.750
	Total	10.19	100	–	–	–

* Soil texture is classified by USDA method.

Due to the fact that understanding the erosion and deposition rates in a catchment is important for designing soil and water conservation measures, two simultaneous researches which emphasizes on the measurement of soil erosion at plot and catchment scales were conducted on tree coffee based crop. The research is aimed to measure and compare soil erosion from both scales as the basic data of integrated recommendation of the soil and water conservation at that region.

2. Materials and methods

2.1 Study site and soils

The soil erosion experiment was conducted in the rainy seasons of 2000/2001 and 2001/2002, while sediment yield observation was conducted in the rainy season of 2001/2002. The research sites are located at Bodong Jaya sub village, Sukajaya village, Sumber Jaya sub district, West Lampung regency, Sumatra Island, Indonesia. The geographic position is approximately situated around 105° 26' E and 05° 02' S. According to the Soil Taxonomy Classification (Soil Survey Staff, 1998), the soil is Vertic Dystrudepts. This soil is dominated by clay fraction in all depths, has high exchangeable Al (0.86 – 7.86 cmol kg^{-1}), medium organic carbon (0.72 – 3.31%), acid to very acid (pH 3.9 – 4.5), high porosity (0.57 – 0.68 m^3 m^{-3}), and low bulk density (0.88 – 1.09 g cm^{-3}). Some selected soil properties from representative profile are presented in Table 1.

As shown in Table 1, the fine roots still could be found in the soil layer until 153 cm-depth. The soil texture is dominated by clay fraction, and as a consequent, cracks were found from the topsoil until the B-horizon. The thin A-horizon indicated that soil erosion has taken place and part of the topsoil was carried away.

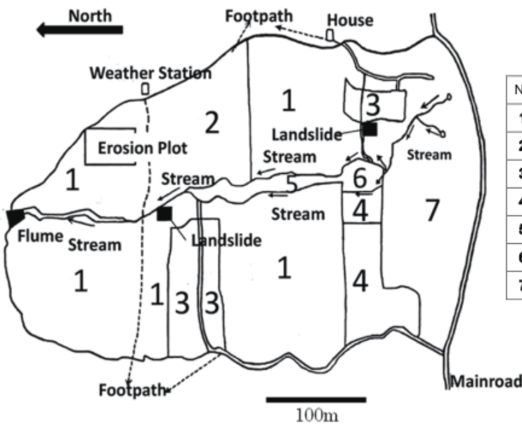
2.2 Rainfall

The amount of rainfall was observed manually and automatically. The "pulse counter type" which recorded every rainfall event (one pulse: 0.5 mm), was used and manual ombrometer was also used for recording rainfall manually.

2.3 Catchment experiment

2.3.1 Catchment description

The catchment area is 10.2 ha. The areas were dominated by steep slopes, with average gradient of about 48 %. Based on altimeter measurement, the highest altitude in catchment was 934 m above sea level (asl) and the lowest was 862 m asl at the outlet of the catchment. The stream length was 263 m, and flows between the paddy field area and hillside, so one side of the catchment occupied by upland areas flowed directly into the creek, and the other side flowed from paddy field areas. The land use was dominated by coffee tree with various type of management and the main land use type is shown in Table 2 and the distribution of land use is shown in Fig. 1. The soil fraction of the catchment from 0 to 20 cm depth in every land use type was also dominated by clay fraction. The clay fraction is more than 60 %.



No.	Landuse
1	Coffee with tree crops
2	Coffee in monoculture
3	Coffee with various cash crop
4	Coffee with vegetable crop
5	Chilli
6	Rice field
7	Shrub

Fig. 1 Land use of experimental catchment.

2.3.2 Streamflow measurement

Parshall-flume (Fig. 2) was set up at the outlet of the catchment to monitor the streamflow leaving the catchment. The changing of water depth in Parshall flume was monitored using an automatic water level recorder (AWLR), which was installed near the Parshall flume; the chart of the AWLR was changed daily. Based on the rating curve derived, the stream flow was calculated.

The Parshall flume was calibrated twice, before and after installation. Calibration was done using the floating method. However for low discharge (water level < 0.5 cm), the volumetric method was applied; this was done by measuring the volume of water, which flowed from the Parshall flume a certain time. A discharge-rating curve was calculated with the following equation:

$$Q = \alpha h^{\beta} \quad (1)$$

where Q is discharge (L s^{-1}), h is water depth in Parshall flume (cm), α and β are constants.

The mean daily flow data was calculated by averaging the water discharge from morning 7:00 to next morning 7:00. Hydrograph component was separated into base flow and direct runoff (quick flow) using the straight-line method.

2.3.3 Sediment yield

Water sample of about 500 mL, was taken at the outlet of the Parshall flume site. The water sampling was done as follows: (1) Two times a day around 7:00 and 17:00 if there was no rain. (2) Several times during rainfall or runoff event from the beginning of direct runoff until the streamflow became lower. (3) Sediment concentration was measured by sieving water sample with paper filter and oven drying it.

Calculations of sediment yield were done by separating into rainfall event and no rainfall event. In case of no rainfall event, the total sediment yield was calculated by averaging the sediment yield taken in the morning 7:00 and in the afternoon 17:00 using the following equation:

$$S_y = \frac{Sd_m + Sd_a}{2} \times Q_d \times 24 \times 3600 \quad (2)$$

where S_y is daily sediment yield (g day^{-1}), Sd_m is sediment concentration (g L^{-1}) taken in the morning 7:00, Sd_a is sediment concentration (g L^{-1}) taken in the afternoon 17:00, Q_d is average daily streamflow (L s^{-1}).

In case of rainfall, the sediment calculation in one day was separated into three rainfall events: before rainfall events, during runoff event, and after runoff was over. The following formula was used to estimate the sediment:

$$S_y = Sd_b \times Q_b \times t_b + \sum_{i=1}^{n} \frac{Sd_{ri}}{n} \times Q_{ri} \times t_{ri} + Sd_o \times Q_0 \times t_0 \quad (3)$$

Fig. 2 The Parshall flume used in the experiment.

where S_y is daily sediment yield (g day^{-1}), Sd_b is sediment concentration before rainfall event (g L^{-1}), Sd_r is sediment concentration during runoff (g L^{-1}), Sd_o is sediment concentration after runoff was over (g L^{-1}), Q_b is average discharge before runoff event (L s^{-1}), Q_r is discharge during runoff event (L s^{-1}), Q_o is average discharge after runoff was over (L s^{-1}), t_b is duration before runoff event (s), t_{ri} is duration of runoff event (s), t_o is duration after runoff event (second), n is the number of sediment sampling during runoff event.

2.4 Soil erosion experiment

2.4.1 Plot treatments

The slope gradient was around 50 % on average for plot soil erosion. Seven plots were constructed and bordered with zinc metal sheets. The plot size was 2.5 m wide and 30 m long. The treatments were as follows: (a) Bare plot: The soil surface was always kept bare as the control plot for the experiment. (b) Natural weeds (NW) plot: The weeds were kept during the experiment time. The natural weed species were *Ageratum conyzoides*, *Paspalum conjugatum*, *Polugala paniculata*, *Hedyotis auricularia*, and *Clibadia surinamense*. *Clibadia surinamense* (woody species), whose height reached 136 cm, was the dominant species (constitute 98 % of the total number of weed species) in natural weed plot. (c) Clean weeded coffee: This treatment was regarded as "control" for coffee management, due to the fact that this was the most popular management in this area. (d) Coffee with NW in strip along the contour line: The weeds were managed along the contour line, behaved like a filter strip (Fig. 3). (e) Coffee with NW in spot weeding: The weeds were cut around the canopy of the coffee tree (Fig. 4). (f) Coffee with *Paspalum conjugatum* (PC) in strip along the contour line. (g) Coffee with PC in spot weeding.

Paspalum conjugatum is one of the weed species of gramineous perennial of South African origin. Its stalks, hard and long, crawl over the ground, putting out irregular roots from the joints. Its growth speed is very fast and the rhizomes are dense. This plant is widely used in both private and public park areas in Indonesia. In addition to these reason, we used *Paspalum* because it was abundant in that area and very easy to manage.

The coffee trees used are Arabusta type, a crossbred between Robusta and Arabica. All the coffee trees were three years old, with planting space of 1.5 m×2 m. The *Paspalum conjugatum* seedlings were planted in October 2000. Soil erosion measurement began at early January 2001, when the *Paspalum* had fully covered the soil surface.

2.4.2 Measurement of soil erosion

Two-collection units were installed at the lower end of each plot. The first unit was a plastic bucket with the capacity of around 20 liters with 30 holes, one hole of which was connected to the second unit of a bottle by vinyl pipe. The design of erosion collection unit is shown in Fig. 5.

The erosion measurement was done every morning if there was rainfall on the previous day. If the bucket was full and there was water sample in the bottle, the runoff and soil erosion was calculated as follows:

$$RO = \frac{V + V_b \times N_b}{A_p} \times 10^{-3} \tag{4}$$

$$E = \frac{S_{ed} + S_{edb} \times N_b}{A_p} \times 10 \tag{5}$$

where RO is runoff (mm), V: runoff volume collected in the bucket (cm^3), V_b is volume of the water trapped by the bottle (cm^3), A_p is plot area (m^2), E is soil erosion (kg ha^{-1}), S_{ed} is oven dry weight of the sediment in bucket (g),

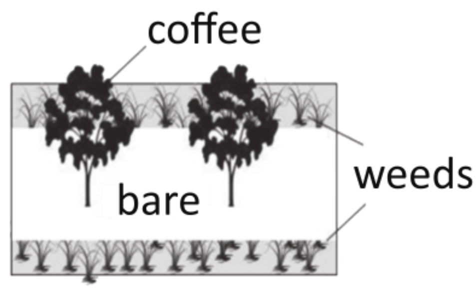


Fig. 3 Coffee in strip along the contour linet.

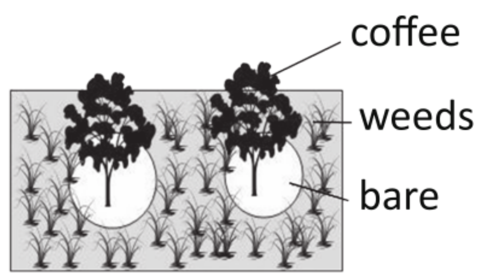


Fig. 4 Coffee in spot weeding.

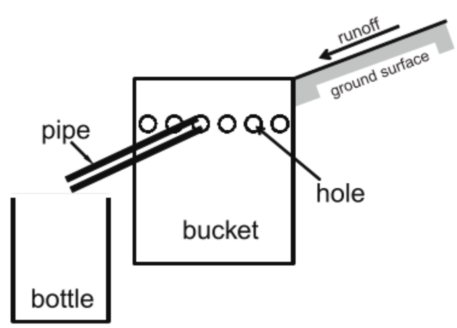


Fig. 5 Design of erosion and runoff collector.

S_{edb} is oven dry weight of the sediment in bottle (g), N_b is the number of hole in the bucket.

3. Results and discussions

3.1 Rainfall

Total rainfall during the experiment period was 2975.3 mm in the year 2001 (from January to December) and 1853.5 mm in 2002 (from January to October). The amount of rainfall in 2002 was probably normal compared to the average rainfall in the areas. Based on 24 years data (1974 – 1998), Afandi et al. (1999) reported that the average rainfall from the adjacent rain gauge station was around 2426 mm year^{-1}, and the maximum rainfall was 3539.5 mm year^{-1}. The monthly rainfall during the experiment time is shown in Fig. 6.

Usually, the dry season starts from June until September. Average monthly rainfall of June, July, August, and September from 1972 to 1998 is 136, 138, 107 and 134 mm, respectively in Sumberjaya. However, during the dry season in 2001, the monthly rainfall amount still exceeds 100 mm as shown in Fig. 6. On the other hands, the dry season in 2002 started at August, and it was very severe because the monthly rainfall was less than 100 mm in August, and even in September and October, the monthly rainfall was less than 50 mm.

Table 3 shows some properties of all rainfall events that was more than 1 mm and contributed soil erosion during the rainy season in 2001/2002. From October 2001 to June 2002, the maximum daily rainfall was 47.5 mm which occurred on January 18, 2002 as shown in Fig. 3. However, this rainfall had very low intensity, 3.4 mm h^{-1}. The maximum intensity in 2001/2002 rainy season was 46.5 mm h^{-1} which occurred on May 8, 2002. This maximum intensity of rainfall had also the maximum value of 30-minutes intensity (I_{30}), in which the amount was 58 mm h^{-1}. From 49 selected rainfall events during 2001/2002 rainy season, the rainfall intensity which was more than 25 mm h^{-1} occurred only 9 times or 18 %, and between 10 – 25 mm h^{-1} was 39 %, about 43 % was less than 10 mm h^{-1}.

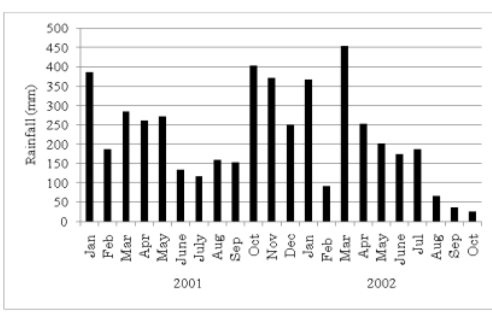


Fig. 6 Monthly rainfall pattern during the experiment time.

Table 3 Rainfall properties during the rainy season in 2001/2002.

	Date	Rainfall R(mm)	Duration T(min)	Intensity R/T(mm h^{-1})
1	2001.10.29	21.5	46	28.0
2	2001.10.30	6.5	21	18.6
3	2002. 1.16	5.0	86	3.5
4	2002. 1.17	13.0	87	9.0
5	2002. 1.18	47.5	840	3.4
6	2002. 1.22	7.0	223	1.9
7	2002. 1.23	4.5	33	8.2
8	2002. 1.24	13.0	29	26.9
9	2002. 1.25	13.0	91	8.6
10	2002. 1.27	3.0	40	4.5
11	2002. 2. 3	3.0	29	6.2
12	2002. 2.10	1.0	64	0.9
13	2002. 2.15	23.0	95	14.5
14	2002. 2.15	2.5	11	13.6
15	2002. 2.28	1.5	45	2.0
16	2002. 3. 1	28.5	53	32.3
17	2002. 3. 5	1.5	17	5.3
18	2002. 3. 5	7.5	32	14.1
19	2002. 3. 8	10.5	117	5.4
20	2002. 3. 9	9.0	112	4.8
21	2002. 3.12	19.0	66	17.3
22	2002. 3.13	22.0	38	34.7
23	2002. 3.13	5.0	212	1.4
24	2002. 3.14	5.0	16	18.8
25	2002. 3.17	40.5	82	29.6
26	2002. 3.18	12.5	104	7.2
27	2002. 3.27	21.5	65	19.8
28	2002. 3.28	6.0	12	30.0
29	2002. 3.28	13.0	101	7.7
30	2002. 4. 5	19.5	188	6.2
31	2002. 4. 6	8.0	112	4.3
32	2002. 4. 9	4.0	19	12.6
33	2002. 4.13	5.0	23	13.0
34	2002. 4.16	6.0	26	13.8
35	2002. 4.18	13.0	56	13.9
36	2002. 4.20	10.0	101	5.9
37	2002. 4.21	16.5	69	14.3
38	2002. 4.25	21.0	53	23.8
39	2002. 5. 8	9.0	28	19.3
40	2002. 5. 8	38.0	49	46.5
41	2002. 5.11	10.0	60	10.0
42	2002. 5.14	4.5	20	13.5
43	2002. 5.14	10.0	44	13.6
44	2002. 5.16	4.0	47	5.1
45	2002. 5.16	20.0	33	36.4
46	2002. 6. 3	9.5	38	15.0
47	2002. 6. 3	8.5	52	9.8
48	2002. 6. 4	9.5	21	27.1
49	2002. 6. 4	19.0	53	21.5

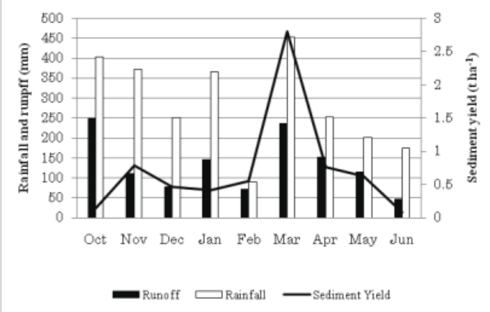


Fig. 7 Runoff, sediment yield, and rainfall during the observation time (from October 2001 to June 2002).

3.2 Runoff and sediment yield

Runoff from the catchment outlet is shown in Fig. 7. As shown in Fig. 7, the monthly streamflow pattern is strongly affected by the monthly rainfall. The maximum monthly streamflow occurred in March when its monthly rainfall was also the highest. The average ratio of streamflow to rainfall was around 49 %, it means that more than 50 % of the monthly rainfall was stored at the catchment in the form of infiltration.

As shown in Fig. 7, the minimum runoff was about 48 mm in June and the maximum was 248 mm in October, and the ratio of max/min runoff was 5.2. It means that the catchment was in a good condition. For Indonesian's catchment, according to Mas'ud et al. (2004), if the ratio between max/min runoff < 50, the catchment is good, and poor if > 120.

As it has already been mentioned in the methodology, the sediment yield estimation was divided into two categories; (i) in case of no rainfall event, and (ii) during rainfall event. During rainfall event, the calculation was also divided into three events: (a) sediment yield before runoff occurred, (b) the sediment yield during runoff event, and (c) the sediment yield after runoff was over. The sediment yields from (b) to (c) reflected the sediment load, which was carried during the soil erosion process. The results are given in Table 4.

The total sediment yield which flowed out from the catchment was 6.6 t ha^{-1} during the rainy season of 2001/2002. The total sediment yield during rainfall events was 4.3 t ha^{-1}, which contributed 64 % of total sediment yield, and the sediment yield during no-rainfall events was 2.4 t ha^{-1} or 36 % of the total sediment yield. The sediment yield was far below the criterion of Ministry of Forestry (2009b) which categorized that if the sediment yield is $<$ 2 mm year^{-1} or about 20 t ha^{-1} year^{-1}, the catchment is good, and if $>$ 5 mm year^{-1} or 50 t ha^{-1} year^{-1}, it's poor.

Various results of sediment yield have been reported were obtained from several catchment studies in Indonesia. On vegetable steep terrace, Sinukaban et al. (1994) reported 42 – 75 t ha^{-1} year^{-1}, while on agricultural bench terrace with mixed rain-fed, van Dijk (2002) reported 40 t ha^{-1} year^{-1}. The value of this experiment is almost similar with Bruijnzeel (2004) who reported the soil loss of 4 t ha^{-1} year^{-1} for Agathis plantation forest, while Rijsdijk (2007a, b) found annual sediment yields from the two volcanic catchment areas to be 22 – 26 and 50 – 87 t ha^{-1} year^{-1}, respectively.

The maximum sediment yield occurred in March 2002 which contributed 53 % of the total sediment, which also correlated with the biggest monthly rainfall (Fig. 6). However in February and May, contribution of sediment yield during no-rainfall events was higher than rainfall events as shown in Table 4. The source of no-rainfall sediment in February was mainly due to the paddy field areas where land was tilled and planted on 17 to 22 January, while small collapse which occurred on the side of the creek produced "streambank erosion" during May.

Although the soil is dominated by clay fraction, the silt and sand fraction were abundant in the sediment load (Table 5). It seemed that these soil fractions were more erodible than clay fractions, and as a consequent the clay fraction was dominant in the area as shown in Table 2.

3.3 Soil loss at erosion plot

The total soil loss from each treatment, which was observed from January 2001 until October 2002, is shown in Table 6. The lowest soil loss was from natural weeds

Table 4 Sediment yield during rainfall and no-rainfall event (from October 2001 to June 2002).

Month	Sediment yield (t ha^{-1})		Sediment yield ratio (%)
	Rainfall event (SR)	No-rainfall event (SN)	$100 \times SR/(SR+SN)$
October	0.11	0.04	73
November	0.60	0.19	76
December	0.24	0.22	52
January	0.31	0.11	75
February	0.15	0.40	28
March	2.28	0.53	81
April	0.44	0.32	58
May	0.10	0.53	16
June	0.06	0.03	65
Total	4.29	2.37	64

Table 5 Soil texture in the sediment yield.

Month	Soil texture* (g g^{-1})		
	sand	silt	clay
December	0.31	0.30	0.39
February	0.37	0.25	0.38
March	0.23	0.34	0.43

* Soil texture is classified by USDA method.

Table 6 Effects of weeds management under coffee tree on soil loss (from January 2001 to October 2002).

Land use type	Soil Loss ($t\ ha^{-1}$)
(a) Bare plot	0.87
(b) Natural weeds	0.12
(c) Clean weeded coffee	0.76
(d) Coffee with natural weeds in strip	0.61
(e) Coffee with natural weeds in spot	0.58
(f) Coffee with *Paspalum* in strip	0.56
(g) Coffee with *Paspalum* in spot	0.56

plot (0.12 $t\ ha^{-1}$) and the highest from the bare plot (0.87 $t\ ha^{-1}$), while the soil loss from coffee areas was 0.56 – 0.76 $t\ ha^{-1}$, which ranged between the values from natural weed plot and bare plot.

Comparing the results of this experiment to similar experiments in Indonesia, especially in Sumber Jaya, the soil erosion was lower. The previous study by Afandi et al. (2002) showed that the average soil loss from clean-weeded coffee was 1.1 $t\ ha^{-1}\ year^{-1}$, while Dariah et al. (2004) found that the soil erosion from coffee with natural grass in strip was 1.28 $t\ ha^{-1}\ year^{-1}$ and from clean-weeded coffee was 1.5 $t\ ha^{-1}\ year^{-1}$. In plot scale, Gintings (1982) found that the soil loss from 1-year old *Robusta* coffee with 59 – 63 % slope gradient was 1.94 $t\ ha^{-1}$, on the other hand, the soil loss from 3-years old coffee with slope gradient 62 – 66 % measured from May to October was 1.57 $t\ ha^{-1}$.

In addition to the effectiveness of the conservation measures applied, the low soil loss in all treatments was probably due to the soil physical properties and the low rainfall intensity. As shown in Table 1, the soil was deep with some cracks until 1-m depth, so the soil permeability would be fast, and the infiltration would be more than runoff. Dariah et al. (2004) also found that the soil physical properties, especially macro pore and soil permeability, was responsible for the low soil erosion in coffee area in Sumber Jaya.

The interesting soil morphology found in the research area is that almost all of the soil layers have cracks vertically until the fourth layer, more or less than 100 cm from the soil surface. Cracks are rarely found in humid tropical soils, because these minerals are usually weathered intensively and directly to form low activity clays such as kaolinite or even sesquioxides that have low value of coefficient of linear extensibility. The soil cracks are probably due to 2:1 layer silicate mineral, because Wada et al. (1999) found that although the clay fraction in the research area was dominated by hlloysite (66 %), it also contains 25 % of 2:1 layer silicate minerals particularly vermiculite-chlorite intergrade.

3.4 Discussion

The soil erosion from the catchment level was greater than erosion from the plot scale. The sediment yield from the catchment during 8-months' rainfall event was 4.3 $t\ ha^{-1}$, while the soil erosion from coffee areas during one and a half years was only 0.56 – 0.76 $t\ ha^{-1}$. It means that the contribution of sediment yield from agricultural areas were very small. Other erosion sources, such as stream bank erosion, gully erosion, collapse, and footpath were responsible for the high soil erosion at the catchment scale, although the source of previous erosion from agricultural fields could be entrapped inside these sites.

The other studies from Indonesian's catchment showed various results. Bruijnzeel (2004) found that the erosion from catchment roads, settlements and trails which occupied 5 % of the total area, contributed approximately 54 % of the total sediment yield, while rain-fed agriculture which occupied 20 % of the total catchment area contributed 37 % of the sediment yield. On the other hand, Rijsdijk (2005) found that rain-fed agricultural land contributed nearly half of the soil erosion on average, while hillside trails, settlements and roads, and non-surface erosion contributed the rest.

In this research, soil erosion was only measured from the plot scale and catchment, and the other sources of soil erosion were not measured. Due to the fact that from previous studies the soil erosion from coffee areas based on the plot level was very low (Afandi et al., 2002; Dariah et al., 2004). It was amazingly found that the sediment yield from micro-catchment scale in this research was higher than soil erosion rate at the plot scale. However, due to the fact that the sediment yield was taken on daily basis with frequent water sampling during rainfall and calculated sediment yield on daily basis, not estimated it from sediment-discharge rating curve equation as ordinarily used in previous research (Walling, 1977, Asselman, 2000), the accuracy of the sediment yield estimation was very high.

This research showed that at the catchment and plot scales, the soil erosion from the agricultural land is not much although it is dominated by steep slopes, and coffee land use with high clay soil texture. As the effects of slope and land use in agricultural land were very small, the soil-water conservation strategy for this catchment was directed to the other sources of sediment yield, such as road, gully, and collapse. The soil conservation practice in agricultural land strategy must be focused on how to increase infiltration rate, so that direct runoff will be decreased before entering gullies or streams, for example by building silt trap (Fig. 8).

This experiment also showed that the determination of a catchment to be critical or not should be done by soil erosion at both plot and catchment scales. In case of this experiment where the soil erosion in agricultural land is very low, the other factors in addition to traditional soil erosion factors (rain, soil, slope, vegetation, and management) must be considered, such as the permeability of the rock below the soil (geology).

Fig. 8 Silt trap in coffee plantation.

4. Conclusion

This experiment strengthens the previous study that the soil erosion from coffee areas at Sumber Jaya, Lampung, Indonesia, was very low, although the erosion factors were very high, such as rainfall and slope. In fact, the soil erosion from catchment level was greater than erosion plot scale. The sediment yield from the catchment during 8-months observation was 4.3 t ha^{-1}, while the soil erosion from coffee areas during one and a half year was only 0.56 – 0.76 t ha^{-1}. The contribution of sediment yield from agricultural areas was very small, less than 10 %. Other erosion sources, such as stream bank erosion, gully erosion, collapse, and footpath were responsible for the high soil erosion at catchment scale.

The strategies to curtail soil erosion in agricultural field must be continued to reduce runoff before entering gully or stream. This experiment also showed that the determination of a catchment to be critical or not should be done by soil erosion estimations at the plot and catchment scales.

Acknowledgements

The plot soil erosion research was funded by Monbusho under the project title "Assessment of Soil Fertility and Rehabilitation of Cultivated Tropical Rain Forest in South East Asia" led by Dr. Masanori Nonaka, Niigata University, Japan, while the catchment research was funded by ICRAF SEA (Bogor) and ACIAR under the project of title "Micro-catchment soil loss as affected by soil management practices".

References

Afandi, Manik, T.K., Rosadi, B., Utomo, M., Senge, M., Adachi, T. and Oki, Y. (2002): Soil erosion under coffee trees with different weed managements in humid tropical hilly area of Lampung, South Sumatra, Indonesia. J. Jpn. Soc. Soil Phys., 91: 3 – 14.

Asselman, E.M. (2000): Fitting and interpretation of sediment rating curves. J. Hydrol., 234 (3 – 4): 228 – 248.

Braud, I., Vich, A.I.J., Zuluaga, J., Fornero, L. and Pedrani, A. (2001): Vegetation influence on runoff and sediment yield in the Andes region observation and modeling. J. Hydrol., 254(1 – 4): 124 – 144.

Bruijnzeel, L.A. (2004): Hydrological functions of tropical forests: not seeing the soil for the trees? Agric. Eco. Env., 104 (1): 185 – 228.

Ceballos, A. and Schnabel, S. (1998): Hydrological behavior of a small catchment in the dehesa landuse system (Extremadura, SW Spain). J. Hydrol., 210 (1-4): 146 – 160.

Dariah, A.F., Agus, S., Arsyad, Sudarsono and Maswar (2004): Erosion and surface runoff in a coffee area at Sumberjaya, West-Lampung (in Indonesia). Agrivita, 26 (1): 52 – 60.

Gintings, A.Ng. (1982): Aliran permukaan dan erosi dari tanah yang tertutup tanaman kopi dan hutan alam di Sumberjaya, Lampung Utara. Report No. 339. Balai Penelitian Hutan, Pusat Penelitian dan Pengembangan Kehutanan, Bogor.

Li, M., Zhanbin Li,Z., Yao, W. and Liu, P. (2009): Estimating the erosion and deposition rates in a small watershed by the 137Cs tracing method. Appl. Radiat. Isot., 67 (2): 362 – 366.

Mas'ud, A.F., Nugroho, S.P. and Irfan, B.P. (2004): Criteria and indicators of watershed management used for the national movement for land and forest rehabilitation (GNRHL) in Indonesia. In : Agus, F., Farida, and van Noordwijk, M., (eds): Hydrological impacts of forest, agroforestry and upland cropping as a basis for rewarding environmental service providers in Indonesia, World Agroforestry Centre (ICRAF), Bogor, Indonesia: 51 – 64.

Ministry of Forestry and Estate (1999): Lampiran Keputusan Menteri Kehutanan dan Perkebunan No.284 tentang Penetapan Urutan Prioritas Daerah Aliran Sungai, The Decree of Ministry of Forestry and Estate No.284, Republic Indonesia about the watershed priority. Ministry of Forestry and Estate, Republic of Indonesia, Jakarta, Indonesia: 1.

Ministry of Forestry (2009a): Lampiran Keputusan Menteri Kehutanan Republik Indonesia No.328 tentang Penetapan Daerah Aliran Sungai (DAS) Prioritas Dalam Rangka Rencana Pembangunan Jangka Menengah Tahun 2010 – 2014. The Decree of Ministry of Forestry No.328, Republic Indonesia about the watershed priority for 2010 – 2014, Ministry of Forestry , Republic of Indonesia, Jakarta, Indonesia: 2.

Ministry of Forestry (2009b): Lampiran Peraturan Direktur Jendral Rehabilitasi dan Perhutanan Sosial Tentang Pedoman Monitoring dan Evaluasi Daerah Aliran Sungai No.P.04/V-SET/2009, The Rule of Directorate General of Rehabilitation and Social Forestry about Guidance of Monitoring and Evaluating of Catchment No.P.04/V-SET/2009, Ministry of Forestry, Republic of Indonesia, Jakarta, Indonesia: 25 – 33.

Rijsdijk, A. (2005): Evaluating sediment sources and delivery in a tropical volcanic watershed. IAHS Publication, 292: 16 – 23.

Rijsdijk, A., Sampurno Bruijnzeel, L.A. and Prins. Th.M. (2007a): Sediment yield from gullies, riparian mass wasting and bank erosion in the Upper Konto catchment, East Java, Indonesia. Geomorphology, 87 (1-2): 38 – 52.

Rijsdijk, A., Sampurno Bruijnzeel, L.A. and Kukuh Sutoto, C. (2007b): Runoff and sediment yield from rural roads, trails and settlements in the upper Konto catchment, East Java, Indonesia. Geomorphology, 87 (1-2): 28 – 37.

Sihite, J. (2001): Evaluasi Dampak Erosi Tanah : Model Pendekatan Ekonomi Lingkungan dalam Perlindungan DAS: Kasus Sub-DAS Besai-DAS Tulang Bawang, Lampung, Evaluation of Soil Erosion Impact: Economic valuation of land use changes in Besai Subwatershed-Tulang Bawang Lampung. Southeast Asia Policy Research Working Paper, No. 11. ICRAF SE-Asia, Bogor, Indonesia: 86 pp.

Sinukaban, N., Pawitan, H., Arsyad, S., Amstrong, J. and Nethery, M. (1994): Effect of soil conservation practices and slope length on runoff, soil loss, and yield of vegetables in West Java, Indonesia. Australian J. of Soil and Water Conservation, 7: 25 – 29.

Soil Survey Staff (1998): Keys to Soil Taxonomy, Eighth Ed. USDA-Natural Res. Conserv. Serv., Washington D. C.

Steegen, A., Govers, G., Takken, I., Nachtergaele, J., Poesen, J. and Merckx, R. (2001): Factors controlling sediment and phosphorus export from two Belgian agricultural catchments. J. Environ. Qual., 30: 1249 – 1258.

Syam, T., Nishide, H., Salam, A.K., Utomo, M., Mahi, A.K., Lumbanraja, J., Nugroho, S.G. and Kimura, M. (1997): Land use change in a hilly area of south Sumatra, Indonesia (from 1970 to 1990). Soil Sci. Plant Nutr., 43(3): 587 – 599.

van Dijk, A.I.J.M. (2002): Water and sediment dynamics in bench terraced agricultural steeplands in West Java, Indonesia. PhD Thesis, Vrije Universiteit, Amsterdam: 378.

Verbist, B., Dinata Putra, A.E. and Budidarsono, S. (2005): Factors driving land use change —Effects on watershed functions in a coffee agroforestry system in Lampung, Sumatra—. Agricultural Systems, 85: 254 – 270.

Wada, S.I., Syam, T. Sarno and Lumbanraja, J. (1999): Mineralogical properties of soils in hilly and middle terrace areas of south Sumatra, Indonesia. Can biological production harmonize with environment?: Reports from research sites in Asia. Proc. Int. Symp. at the United Nations University, 1999: 227 – 230.

Walling, D.E. (1977): Assessing the accuracy of suspended sediment rating curves for a small basin. Water Resour. Res., 13: 531 – 538.

要　旨

圃場レベルで実測した土壌侵食量の結果を流域レベルに拡大して適用すると問題が発生することが多い．すなわち，流域内で生起している複雑な水文現象から，圃場レベルの土壌侵食量と流域スケールで測定した侵食量は一致しないことが多い．そこで，インドネシア国ランポン州のコーヒー樹が栽培されている地域を対象に，圃場レベルと流域レベルでの土壌侵食量を実測することを目的として，10.2 ha の試験流域と，その流域内に 75 m^2 の試験圃場を 7 試験区設けた．試験圃場の構成は，(a) 裸地区（対照区），(b) 自然植生区，(c) 雑草を完全に除去したコーヒー栽培区，(d) 圃場面を *Paspalumconjugatum*（以下 PC）によって被覆しコーヒー樹の回りのみを除草したコーヒー栽培区，(e) 等高線方向に PC を帯状に移植したコーヒー栽培区，(f) 圃場面を自然植生の雑草（以下，NM）で被覆しコーヒー樹の回りのみを除草したコーヒー栽培区，(g) 等高線方向に NW を帯状に移植したコーヒー栽培区，である．1 年半の実測結果から，圃場試験区からの土壌侵食量は，0.12 t ha^{-1} ((b) 自然植生区）から 0.87 t ha^{-1}（(a) 裸地区）の範囲にあった．一方，8 ヶ月間の雨季における試験流域からの土壌流出量は 6.7 t ha^{-1} であった．以上の試験結果から，流域レベルにおける単位面積当たりの土壌侵食量は，圃場レベルの侵食量の 10 倍以上の値を示した．これは，流域からの土壌侵食量は，ガリ侵食，地滑り，流域内の水田からの土壌侵食に起因すると想定される．以上のことから，現在，耕地からの侵食対策に重点がおかれた土壌保全は再考すべきであり，他の土壌侵食発生源にも対策を講じ，下流への土壌流出を削減しなければならないことを示唆している．

キーワード：流域，コーヒー，インドネシア，土壌流出，土壌侵食

Soil erosion from catchment and plot scales under coffee tree based crop in humid tropical climate of Lampung, Indonesia

ORIGINALITY REPORT

7%	%	7%	0%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	Verbist, B.. "Factors affecting soil loss at plot scale and sediment yield at catchment scale in a tropical volcanic agroforestry landscape", Catena, 20100115 Publication	1%
2	"Agroforestry Systems in India: Livelihood Security & Ecosystem Services", Springer Science and Business Media LLC, 2014 Publication	1%
3	Mian Li, Zhanbin Li, Wenyi Yao, Puling Liu. "Estimating the erosion and deposition rates in a small watershed by the 137Cs tracing method", Applied Radiation and Isotopes, 2009 Publication	1%
4	Submitted to British University In Dubai Student Paper	<1%
5	"Gully Erosion Studies from India and Surrounding Regions", Springer Science and Business Media LLC, 2020	<1%

Publication

6	I. Braud, A.I.J. Vich, J. Zuluaga, L. Fornero, A. Pedrani. "Vegetation influence on runoff and sediment yield in the Andes region: observation and modelling", Journal of Hydrology, 2001 Publication	<1 %
7	Rahmah Dewi Yustika, Hiroaki Somura, Slamet Budi Yuwono, Bustanul Arifin, Hanung Ismono, Tsugiyuki Masunaga. "Assessment of soil erosion in social forest-dominated watersheds in Lampung, Indonesia", Environmental Monitoring and Assessment, 2019 Publication	<1 %
8	Rijsdijk, A.. "Sediment yield from gullies, riparian mass wasting and bank erosion in the Upper Konto catchment, East Java, Indonesia", Geomorphology, 20070601 Publication	<1 %
9	J. Moravcová, T. Pavlíček, P. Ondr, M. Koupilová, T. Kvítek. "Comparison of parameters influencing the behavior of concentration of nitrates and phosphates during different extreme rainfall-runoff events in small watersheds", Hydrology and Earth System Sciences Discussions, 2013 Publication	<1 %

10	"Perspectives on Environmental Management and Technology in Asian River Basins", Springer Science and Business Media LLC, 2012 Publication	<1 %
11	Cuomo, Sabatino, Maria Della Sala, and Mariarosaria Pierri. "Experimental evidences and numerical modelling of runoff and soil erosion in flume tests", CATENA, 2016. Publication	<1 %
12	Yongqiu Wu, Qiuhong Zheng, Yongguang Zhang, Baoyuan Liu, Hong Cheng, Yanzai Wang. "Development of gullies and sediment production in the black soil region of northeastern China", Geomorphology, 2008 Publication	<1 %
13	Baptista, I., C. Ritsema, A. Querido, A.D. Ferreira, and V. Geissen. "Improving rainwater-use in Cabo Verde drylands by reducing runoff and erosion", Geoderma, 2015. Publication	<1 %
14	Bruno Verbist, Andree Eka Dinata Putra, Suseno Budidarsono. "Factors driving land use change: Effects on watershed functions in a coffee agroforestry system in Lampung, Sumatra", Agricultural Systems, 2005 Publication	<1 %

15 Yasar Karadag, Ugur Buyukburc. "Forage qualities, forage yields and seed yields of some legume–triticale mixtures under rainfed conditions", Acta Agriculturae Scandinavica, Section B - Soil & Plant Science, 2004
Publication
<1 %

16 "Statistical Analysis of Hydrologic Variables", American Society of Civil Engineers (ASCE), 2019
Publication
<1 %

17 A. Watanabe. "Assessment of degradation and generation of humus in a coffee soil affected by weed cover by means of a stable carbon isotopic ratio", European Journal of Soil Science, 1/22/2007
Publication
<1 %

18 Martinez-Casasnovas, J.A.. "The cost of soil erosion in vineyard fields in the Penedes-Anoia Region (NE Spain)", Catena, 20061231
Publication
<1 %

19 "Advances in Integrated Soil Fertility Management in sub-Saharan Africa: Challenges and Opportunities", Springer Nature, 2007
Publication
<1 %

20 A. I. J. M. Van Dijk. "A methodology to study rain splash and wash processes under natural rainfall", Hydrological Processes, 01/2003
<1 %

Publication

21	I. D. U. H. Piyathilake, R. G. I. Sumudumali, E. P. N. Udayakumara, L. V. Ranaweera, J. M. C. K. Jayawardana, S. K. Gunatilake. "Modeling predictive assessment of soil erosion related hazards at the Uva province in Sri Lanka", Modeling Earth Systems and Environment, 2020 Publication	<1 %
22	Nishant Kumar Srivastava. "Role of selected riparian herbs in reducing soil erosion and nutrient loss under simulated rainfall", Environmental Earth Sciences, 11/24/2009 Publication	<1 %
23	P Marbun, Z Nasution, H Hanum, A Karim. "Classification of andisol soil on robusta coffee plantation in Silima Pungga - Pungga District", IOP Conference Series: Earth and Environmental Science, 2018 Publication	<1 %
24	Rodríguez-Blanco, M.L., M.M. Taboada-Castro, and M.T. Taboada-Castro. "Linking the field to the stream: Soil erosion and sediment yield in a rural catchment, NW Spain", CATENA, 2013. Publication	<1 %
25	Wang, Guoqiang, Binbin Wu, Lei Zhang, Hong Jiang, and Zongxue Xu. "Role of soil erodibility in affecting available nitrogen and	<1 %

phosphorus losses under simulated rainfall", Journal of Hydrology, 2014.
Publication

26	Mayor, A.G.. "Post-fire hydrological and erosional responses of a Mediterranean landscpe: Seven years of catchment-scale dynamics", Catena, 20070901 Publication	<1 %
27	Hellin, . "Agro-ecological Components of Better Land Husbandry", Better Land Husbandry From Soil Conservation to Holistic Land Management, 2006. Publication	<1 %

Exclude quotes	On	Exclude matches	Off
Exclude bibliography	On		