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Soil Erosion under Coffee Trees with Different Weed Managements in Humid Tropical Hilly Area of Lampung, South Sumatra, Indonesia

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Abstract

Soil loss and surface runoff from farmland under coffee trees with different weed managements were investigated in Lampung, South Sumatra, Indonesia during rainy seasons from 1996 to 1999. Three treatment practices investigated were as follows : coffee without cover crop ; coffee with *Paspalum conjugatum* sp. as cover crop, and coffee with natural weeds. Weed management was done every two week by clearing all the weeds in coffee plot, and cutting the weeds around the coffee trees with diameter 1 m for the weedy plots. The results showed that the maximum daily rainfall and intensity based on 10 minutes observation were 82 mm/day and 120 mm/h, however, only 14.2% of rainfall intensities was greater than 25 mm/h (classified as erosive rainfall intensity). A relationship between erosivity index (R) and daily rainfall (X) was found as follows : R＝1.624 (X-10.9), where R : daily erosivity index ($m^2 \cdot t/ha/h$) and X : daily rainfall (mm/day). The runoff ratio for clean-weeded coffee ranged from 7.0 to 15.9%, and decreased after the second year because of the coffee canopy growth. The presence of *Paspalum conjugatum* had reduced runoff until zero after the third year, whereas in natural weeds plot, runoff became zero after the fourth year. The highest soil loss was found in clean-weeded coffee which reached 22.7 t/ha in the second year of experiment. The use of cover crop could suppress soil loss until zero after the third year in *Paspalum* plot and after the fourth year in natural weeds plot. However the good management of weeds as cover crops is necessary due to the bad performance of coffee growth at both weedy plots. The average soil loss from clean-weeded coffee plot was 1.24 mm per year which was below the soil formation rate in Indonesia.

Key words : coffee, soil erosion, runoff, erosivity index

1. Introduction

Lampung, located in the southern part of Sumatra Island, is one of the biggest coffee producing districts in Indonesia. About 50% of coffee production of Indonesia occurs in Lampung. From 1990 to 1994, the average export of coffee bean from Lampung was 159,970 tons out of 329,070 tons of total Indonesian's coffee export (BPD-AEKI, Lampung, 1996). In 1999, the coffee export from Lampung amounted to 175,800 tons out of 354,000 tons (Bank Indonesia Bandar Lampung, 2000).

The major problem of the coffee management in Lampung is that the coffee trees were mostly planted in steep areas where the soil conservation is usually not applied very well. Clearing up all the ground cover under the coffee plants is the most popular practice for weeding management. The farmers perform such a management practice due to the fact that the coffee root system is abundant around the upper part of the soil surface, so even small weeds like grass type will influence the coffee growth. This reflects on the nutrient component of the coffee leaves due to competition between coffees and weeds if the weeds were left unclear. However, clearing all the weeds promotes soil erosion since this area possesses a humid tropical climate, characterized by abundant rainfall and high rainfall intensity concentrated on rainy season.

It is well known that cropping systems with ground cover maintenance, especially in rainy season, are recommended for farming on slopes in order to reduce soil erosion. Unfortunately, the study of soil loss under coffee plants in the tropics is limited, and a little information is available about soil erosion from coffee areas in Indonesia. An erosion study by Gintings (1982) in Sumber Jaya areas, Lampung, measured soil loss in Robusta coffee under natural condition without any other management. The coffee tree used was 16-yr old for 8-months measurement, and 1-yr and 3-yr old for 6-month measurement. A 6-month erosion study was also conducted in Bali by Pudjiharta and Pramono (1988) in 15-yr old coffee trees. The information derived from the studies was just the amount of soil loss from coffee plantation in a short period. Some researchers in Indonesia also have used some grasses as cover crop, but it was limited for horticultural crop or annual crops, for example Abujamin *et al.* (1983) used *Bahia* and *Bede* grass, and Utomo (1989) reported the using of *King* grass in sandy soil in Indonesia.

Lately, the problem of soil erosion in Lampung, Indonesia, has accelerated the following political changes. Due to weak law enforcement during the reformation period in 1998, the public was encouraged to open the *Calliandra* reforestation areas. In a very short period during 1999, thousand of hectares of protected forest in Sumber Jaya were converted into coffee plantation. The increasing of coffee bean price more than three times also enhanced the forest squattering in 1998.

The current controversies on soil erosion in the coffee-growing areas in Lampung persist due to lack of comprehensive research. Since most coffee farmers in these areas apply clean weeding management, a prompt evaluation of soil loss under existing methods of farming and other alternatives of weed management was in need. Thus, the objective of this four years study was to measure the effects of different weed managements under Arabica coffee plants on the extent of surface runoff and soil loss.

2. Materials and Methods

2. 1 Study site

This study was conducted during the rainy seasons from 1995 to 1999. The study site was located at Sumber Jaya District, Lampung Province, South Sumatra, Indonesia. Geographically, it is located at 105°01' EL and 04°34' SL. The slope gradient was around 15° with the elevation of 780m above the sea level. The average rainfall recorded from 1974 to 1998 was around 2500 mm/year and the air temperature was around 22℃ (Afandi *et al.*, 1999).

The soil had the initial properties as shown in Table 1. The soil was dominated by clay fraction in all depths, however the soil bulk density was very low, which is indicating that the soil was friable and porous. The color of soil profile (up to 100 cm soil depth) was dominated by brown to red color which indicated that the internal drainage was very good. The soil reaction is slightly acid with moderate cation exchange capacity. The soil organic carbon was quite high probably due to the fact that the decomposition rate of organic matter was relatively slow. Based on the above

Table 1　Initial soil characteristics prior to planting

Depth (cm)	pH H2O	Total-N (%)	Organic-C (%)	CEC (cmol/kg)	Texture (%) Sand	Silt	Clay	Bulk density (g/cm^3)
0～10	4.92	0.26	3.48	13.3	25	23	52	0.96
10～20	4.89	0.16	1.86	9.9	25	16	59	0.93
20～35	4.91	0.09	0.89	9.3	26	13	61	0.99
35～60	4.87	0.07	0.82	8.7	26	13	61	0.93
60～100	4.85	0.06	0.82	8.7	28	15	57	—

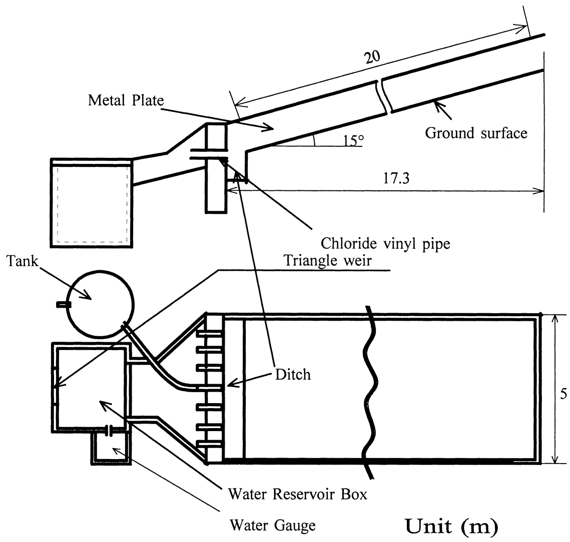

Fig. 1　The design of experimental plot.

soil properties, the soil could be classified as *Latosol* (Indonesian soil classification system) or *Dystrudepts* (Soil Survey Staff, 1998).

2. 2　Treatment plot

The erosion plots were consisted of three plots with 15° gradient, 20 m slope length and 5 m width, and bordered by 30-cm height zinc metal sheets. Two collection units were installed at the lower end of each plot. The first unit was a ditch with the capacity of 0.1 m^3, which was connected to the second unit (a tank and water reservoir) by seven pipes. One pipe, which was in the center, was connected to a tank by a siphon and the others overflowed into the water reservoir box in which a triangle weir and a water gauge were installed. The detailed design of the plot was shown in Fig. 1.

The treatments were as followed :

(1) Treatment 1 (clean-weeded plot) : Ground surface was always keeping bare by hand weeding at two weeks interval. This management is a general practice in this coffee plantation area so that this treatment is regarded as a control.

(2) Treatment 2 (*Paspalum* plot) : Coffee with *Paspalum conjugatum* as cover crop. Young *Paspalum conjugatum* was transplanted to the experiment plot in November 1995 and February 1996.

Paspalum conjugatum is one of weed species, gramineous perennial of the South Africa origin. Its stalks, hard and long, are crawled over the ground, putting out an irregular roots from joints. Its growth speed is very fast and the rhizomes are dense. This plant was widely used in both private and public park areas in

Indonesia.

Instead of these reason, we used *Paspalum* because it was abundant in that area and very easy to manage.

(3) Treatment 3 (natural weeds plot) : Coffee with natural weeds as cover crop.

In each plot, seedlings of Arabica coffee were planted with planting distance 1.5 m by 2 m on November 1995. Weed management was done every two weeks by clearing all the weeds in clean-weeded plot, and cutting the weeds around the coffee tree with diameter 1 m for the weedy plots. Before and after rainy season, the Paspalum mats and natural weeds were mowed at 15-cm height. Application of fertilizer and pesticides had been adopted according to the standard usual practice.

2. 3 Rainfall erosivity

Rainfall was measured by automatic weather station, which recorded every ten minutes. We selected 123 rainfall event data from 1996 to 1999.

The rainfall energy factor was calculated using the equation of Wischmeier and Smith (1978) as follows :

$$EI = E \times I_{30} \quad (1)$$

Where E : total rainfall energy in metric-ton meter per hectare (t·m/ha)

I_{30} : the maximum 30-min rainfall intensity (cm/h)

E was calculated as follows :

$$E = E_k \times r \quad (2)$$

$$E_k = 210 + 89 \log I \quad (3)$$

Where E_k : kinetic energy in metric-ton meter per hectare per centimeter of rain (t·m/ha/cm)

I : rainfall intensity (cm/h)

r : rainfall(cm)

Rain shower less than 0.5 inch and separated from the other rain periods by more than 6 hours was omitted from the erosion index, unless as much as 0.25 inch of rain fell in 15 minutes. According to Wischmeier and Smith (1978), the value of 289 (t·m/ha/cm) was applied for all intensities greater than 7.6 cm/h, so equation (3) will be

$$E_k = 210 + 89 \log I \quad \text{for } I < 7.6\ \text{cm/h} \quad (4)$$

$$E_k = 289 \quad \text{for } I > 7.6\ \text{cm/h} \quad (5)$$

Because energy computed in EI equation is expressed in hundreds of metric-ton per ha (t·m2/ha/h), the erosivity index (R)becomes :

$$R = (E \times I_{30}) \times 10^{-2} \quad (6)$$

2. 4 Soil loss measurement

The sediment in the ditch was pulled out into a drum with a siphon, thoroughly stirring the contents in the drum and quickly extracting 500 ml sample with plastic bottle. By measuring the dry weight and the volume of runoff water stored in the ditch, the soil loss in the ditch was calculated as follows :

$$S_d = (A/500) \times V_d \times 1{,}000 \quad (7)$$

S_d : total soil loss in the ditch (g), A : dry weight of 500 ml water sample (g), V_d : volume of runoff water in the ditch (liter), 1,000 : conversion factor from ml to liter

The sediment in the tank was sampled and the total soil loss in a tank (S_{dr}) was calculated using the same procedure as mentioned above. Total soil loss from erosion plot in an individual measurement was converted into kg/ha as follows :

$$\text{Soil loss} = (S_d + S_{dr} \times 7) \times 100 \times 10^{-3} \quad (8)$$

100 : conversion factor from 100 m0^2 to 1 ha, 10^{-3} : conversion factor from g to kg

2. 5 Supporting data

Supporting data which also had been collected in this study were rainfall and coffee growth parameters. Rainfall data were collected using automatic rainfall recorder every ten minutes ; while coffee growth parameters (height, diameter of canopy, and coffee yield) were measured directly in the field for evaluating the competition between coffees and weeds. The type of weeds and coffee growth parameter were observed by Sriyani *et al.* (1999).

2. 5. 1 Weed vegetation

Although the weeds were cut regularly every two weeks, some weed species were still appeared in clean-weeded plot. As presented in Table 2 reported by Sriyani *et al.* (1999), the dominant weed species in clean-weeded plot was *Ageratum conyzoides* which was an annual

Table 2 Type of weeds species found in each treatment

Clean-weeded plot	*Paspalum* plot	Natural weeds plot
Ageratum conyzoides	*Paspalum conjugatum*	*Clibadia surinamense*
Borreria repens	*Polygala paniculata*	*Clidemia herta*
Erechtites valeriaifolia	*Hedyotis auricularia*	*Chromolaena odorata*
Imperata cylindrica	*Ageratum conyzoides*	*Melastoma affine*
Oxalis barrelieri	*Borreria repens*	*Imperata cylindrica*

herb. Instead of *Paspalum conjugatum*, a few weed species also occurred in *Paspalum* plot including *Polygala paniculata*, *Hedyotis auricularia*, and *Ageratum conyzoides*. *Clibadia surinamense* (woody species) whose mean plant height reached 136 cm was the dominant species (occupy 98% of the total number of weed species) in natural weeds plot. The photos of dominant weed species were shown in Fig. 2.

The weeds started to cover the entire ground surface (100% covered) around March 1996 at *Paspalum* plot and on April 1996 at natural weeds plot. After that, the weeds were managed by spot weeding with diameter 1 m around the coffee tree, and the coverage of weeds, the ratio of the area occupied by weeds to total areas, was calculated as 69%. So, during the experiment period, the weeds covered the soil surface between 69% (after spot weeding) and 100% (before spot weeding).

2. 5. 2 Coffee growth

The existence of weeds has influenced on the coffee growth. The conventional weed management (cleaning up weed) gave the best performance of coffee growth as shown in plant height, canopy diameter and coverage. The weeds had suppressed the coffee height at *Paspalum* plot about 40% and at natural weeds plot about 30%. The canopy diameter was also suppressed as much as 57 % at *Paspalum* plot and 54 % at natural weeds plot.

Due to the bad performance of coffee growth at both weedy plots, the coffee yields of the weedy plots were very low. As reported by Sriyani *et al.* (2000), the yield reduction of coffee beans in weedy plots in 1999 was 40% at *Paspalum* plot and 75% at natural weeds plot

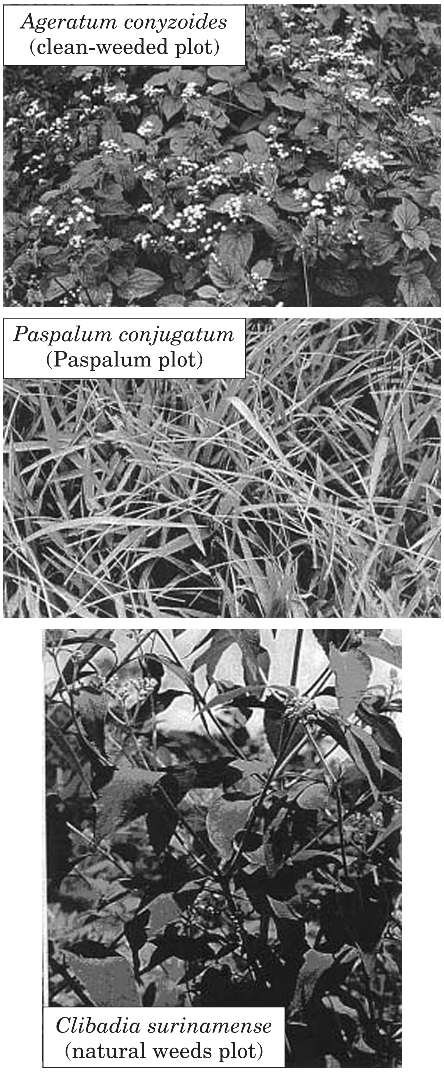

Fig. 2 Dominant species of weed in each experimental plot.

Table 3 Rain erosivity data during 4 years experiment

Year of experiment	R (t·m²/ha/hr)	Rainfall (mm)	Average Rainfall from nearest rainfall station*) (mm)
1st	385.6	456.1	
2nd	511.6	1074.2	
3rd	1547.8	1768.8	
4th	922.0	1248.5	
Total	3367.0	4547.6	
Average	841.8	1136.9	1893.8

*) Calculated from 2 rainfall stations (Pajar Bulan and Sumber Jaya) for rainy season data (Nov. to May) from 1974～1998

compared to clean-weeded plot.

3. Results and Discussion

3. 1 Rainfall Pattern

Table 3 shows that the total rainfall during four years of experimental period was 4547.6 mm, with 1136.9 mm per rainy season. This rainfall was lower than average rainfall occurring in this area, i.e. 1893 mm per rainy season (Afandi *et al.*, 1999) since El Nino's occurrence in 1997 caused a long dry season with low rainfall. In addition, due to plot construction during the first year, the experiment began late, in February 1995, whereas the rainy season usually occurred from October to April or May.

The daily rainfall distribution (Fig. 3) showed that 48% of the rainfalls occurred less than 5 mm/day or about 63% was less than 10 mm/day. Based on the equation (9) described later, about 37% of the daily rainfall could be categorized as the daily erosive rain (＞10.9 mm/day).

The maximum intensity was 20 mm in 10 minutes or 120 mm/h, which occurred at March 6, 1999. According to Hudson (1976), the soil erosion will be occurred if rainfall intensity＞25 mm/h, and as it was shown in Fig. 4, only 14% of the rainfall intensities which were calculated based on 10-minutes time interval could be classified as erosive (＞25 mm/h).

The maximum daily rainfall was 82 mm/day occurred at January 17, 1998, which almost concentrated in two hours and its maximum intensity was 13.5 mm in 10 minutes or 81 mm/hr. As shown in Fig. 5, this rainfall was fallen in 5

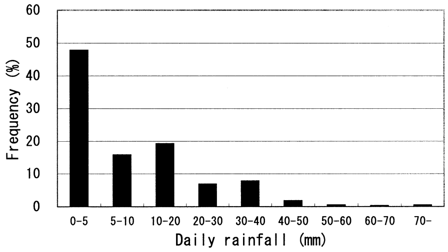

Fig. 3 Distribution of daily rainfall.

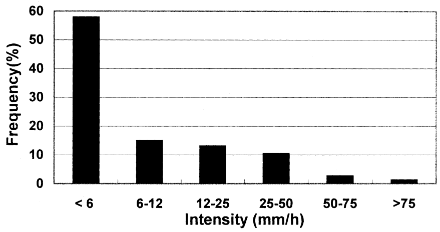

Fig. 4 Distribution of rainfall intensities based on 10-minutes time interval of rainfall.

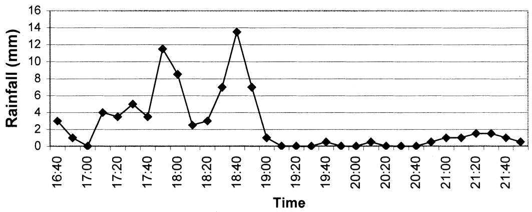

Fig. 5 Pattern of rainfall Indonesia, occurred at January 17th, 1998.

hours, with intermittent pattern; twenty minutes after the rain started, it stopped, and began again for about two hours and ten minutes. The intermittent pattern is a typical rainfall in this area, so several rainfall events could occur in one day. Due to this rainfall character, the rain which fell later could be more erosive although smaller than the previous rainfall, because the soil has been already wet and easy to disperse.

3. 2. Erosivity Index

The value of erosivity index ranged between 385.6–1547.8 and was tabulated in Table 3. Since the measurement period for each rainy season is not the same, the erosivity values differ much. In the first year experiment, the measurement period was only two months due to the erosion plot construction. A long dry season due to *El-Nino* occurred during the second year of experiment until the end of 1997, thus the amount of rainfall was meager although the length of the rainy season was normal. Hence, normal value was probably found in the third and fourth year of measurement, and the values were 1,547.8 and 922.0 (ton $\cdot m^2/h/ha$) respectively.

The rainfall erosivity index as calculated in equation (6) proved to be the optimal rain parameter in Indonesia as indicated by Suwardjo (1981) and Utomo (1989). Utomo (1989) reported the values between 913–1,633 (ton$\cdot m^2/h/ha$) for several areas in Indonesia which agreed with the normal values in this experiment.

3. 3 Relationship between daily rainfall and erosivity index

Based on 123 rainfall events from 1995 to 1999 (Fig 6), a relationship between erosivity index which was calculated using equation (4), (5), and (6) and observed daily rainfall was derived as follows:

$$R = 1.624\ (X - 10.9) \tag{9}$$

with $r^2 = 0.82$

Where R : daily erosivity index ($t \cdot m^2/h/ha$)

X : daily rainfall (mm)

From this equation which shows the linear relationship between R and X, it can be inferred that the rainfall will be erosive if the amount of rainfall exceeded 10.9 mm per day. Due to the fact that the rainfall data available in Indonesia was mostly daily rainfall, some researchers had proposed rain erosivity index using daily rainfall data. The rainfall erosion index widely used in Indonesia as rain erosivity factor for applying USLE was introduced by Bols (1978) as follows:

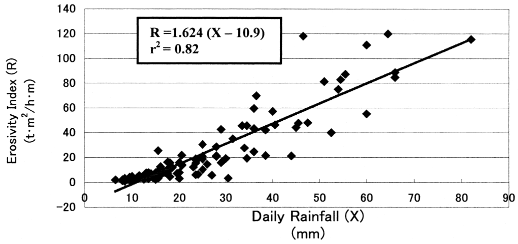

Fig. 6 Relationship between daily rainfall and erosivity index.

$$EI_m = 6.119\ (CH_b)^{1.21}\ (HH)^{-0.47}\ (CH_{24})^{0.53} \tag{10}$$

where:

EI_m : monthly rain erosivity index ($t \cdot m^2/h/ha$)

CH_b : monthly rainfall data (cm)

HH : monthly rainfall event (days)

CH_{24} : the amount of maximum rainfall in 24 hours during one month (cm)

Applying the observed rainfall data to equation (10), the values of EI_m between 532 and 3,370 ($t \cdot m^2/h/ha$) with a mean of 1,845($t \cdot m^2/h/ha$) were obtained in this experiment. These values were two fold higher than Wischmeier and Smith's rain erosivity index (equation (4) and (5)). As shown in Table 3, the Wischmeier and Smith's rain erosivity index ranged from 385.6 to 1547.8($t \cdot m^2/h/ha$) with a mean of 841.8 ($t \cdot m^2/h/ha$). An estimated rain erosivity index between 900 and 2,500 ($t \cdot m^2/h/ha$) were also found for Lampung areas (Manik and Afandi, 1998) that were also higher than the values found in this experiment.

3.4 Surface runoff

The presence of weeds as well as the diameter of coffee canopy influenced the runoff ratio very significantly. As shown in Table 4, in the

Table 4 Runoff and runoff ratio of each rainy season

Rainy Season	Period	Rainfall (mm)	Runoff (mm)			Runoff Ratio (%)		
			Clean-weeded	*Paspalum*	Natural weeds	Clean-weeded	*Paspalum*	Natural weeds
1st	96 Jan.～96 Apr.	467.6	74.5	6.8	42.1	15.9	1.5	9.0
2nd	96 Oct.～97 Apr.	1078.2	97.5	0.5	3.3	9.0	0.0	0.3
3rd	98 Jan.～98 Jun.	1769.4	169.3	0.0	68.3	9.6	0.0	3.9
4th	99 Jan.～99 Jun.	1248.5	87.3	0.0	0.0	7.0	0.0	0.0
Total		4563.7	428.6	7.3	113.7			

first year of experiment, the average runoff ratio was very high (15.9%, 1.5 %, and 9.0 % for clean-weeded plot, *Paspalum* plot, and natural weeds plot respectively) compared to the other years, since the soil surface was relatively open. The runoff ratio from the second to fourth year experiment was 9.0 %, 9.6 % and 7.0% for clean-weeded plot ; 0% for *Paspalum* plot ; and 0.3%, 3.9% and 0% for natural weeds plot.

Although the total runoff of clean-weeded plot increased during the second year of experiment, its runoff ratio decreased due to the increase of the coffee tree canopy. The increase in coffee coverage also reduced the runoff ratio in the fourth year of experiment although the rainfall was fairly high.

The runoff ratio for clean-weeded plot was higher than that found by Gintings(1982) in Sumber Jaya areas. Without cover crops, he found a runoff ratio of 1.78% for 1-years old coffee with 59～63% slope gradient, and 3.39 % for 3-years old coffee with slope gradient 62～66%.

It was interesting to note that the *Paspalum conjugatum* and natural weeds could reduce the surface runoff drastically. *Paspalum conjugatum* is a grass weed type, so the canopy fully crept over the ground surface and its root system was very dense and large. As a consequence, *Paspalum conjugatum* could intercept the rainfall effectively and would act as runoff barrier, thereby inhibiting the surface runoff significantly. Since the internal drainage of soil profile was very good, the runoff water would infiltrate into the soil.

As shown in Table 2, a weed of tree type called *Clibadia surinamense* was present at natural weeds plot and could behave as a shading tree. As consequence, the soil surface was not fully covered with grass weeds type, so the surface runoff was greater than *Paspalum* plot.

The effectiveness of cover crop in reducing runoff was clearly shown in Table 4. In *Paspalum* and natural weeds plot, the increasing of rainfall did not increase runoff height. However, there exists a tendency in clean-weeded plot that runoff height would increase with rainfall.

3.5 Soil loss

The amount of soil loss in every month and the total soil loss during the experimental period are shown in Fig. 7, Fig. 8, and Table 5.

In the first year of experiment, the soil loss from each treatment during the three months observational period (Feb-April 1996) was as follows : 8.8 t/ha in clean-weeded plot, 2.7 t/ha in *Paspalum* plot, and 1.5 t/ha in natural weeds plot. Before the weeds covered the ground surface, there was a little difference in soil loss as shown in February 1996 ; soil loss from *Paspalum* plot was higher than the other plots due to the fact that the ground surface was not covered yet and was disturbed by transplanting *Paspalum* seedlings at this plot. One month later (March 1996), this situation was changed drastically after the weeds began to cover the ground surface ; the soil erosion from clean-

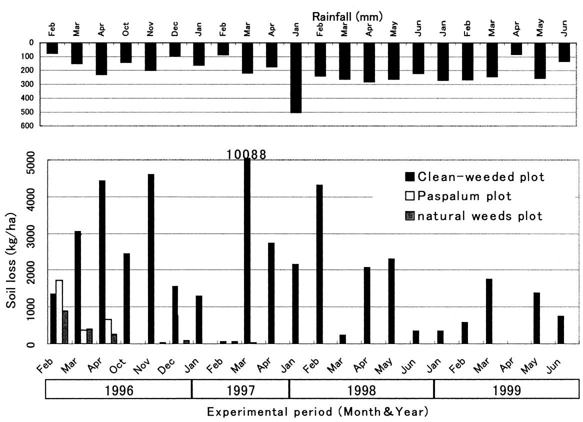

Fig. 7　Monthly soil loss under coffee tree with different weed management.

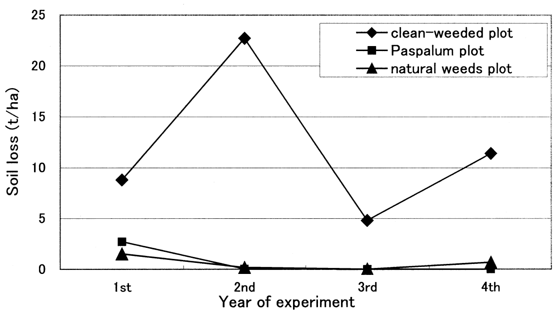

Fig. 8　Soil under coffee tree with differemt weeds management.

-weeded plot increased sharply.

The second year experiment began in October 1996 and continued until April 1997. The soil loss from coffee plot with general weed management (clean-weeded plot) in the second year of experiment was 22.7 t/ha, however it could be 0.028 t/ha if covered with *Paspalum conjugatum* and 0.16 t/ha in natural weeds plot. The weeds had already covered totally the ground surface in *Paspalum* plot and natural weeds plot (100% covered). However there were big differences in weeds species (Table 2), which affected the amount of soil loss. *Paspalum* plot was dominated by *Paspalum conjugatum*, which was very effective in preventing soil erosion due to the fact that ground surface was covered densely with *Paspalum* whose canopy and root system would act as runoff barrier and catch the direct raindrops and prevent surface runoff from flowing over the ground surface. The natural weeds were dominated by woody species and not so dense compared to *Paspalum* plot. Thus, a chance for rainfall to pass the canopy and overflow on the ground surface among the weeds existed.

Due to the long dry season in 1997 because of *El-Nino* effects, the third observation began in 1998 for rainy season of 1997/1998 and the fourth observation began in 1999 for rainy season of 1998/1999. The soil loss from coffee with weeds was very small compared to clean-weeded plot. The soil loss in 1998 from clean-weeded plot was 9.1 t/ha followed by natural weeds plot 0.67 t/ha, and no erosion was found in *Paspalum* plot. In 1999, the soil loss from clean-weeded plot was 4.8 t/ha, and there was no soil loss in both weedy plots.

Compared to the other research data with different crops in Indonesia, the soil loss from the coffee areas was meager. However, comparing with the findings of Gintings (1982) in coffee areas in Sumber Jaya, soil loss appeared higher. The maximum soil loss in this experiment was found in clean-weeded coffee as much as 22.7 t/ha. Utomo (1989) reported that the soil loss from a bare plot could be 423 t/ha. During the four years experimental period from 1976 to1980, Abujamin *et al.* (1983) found soil loss from bare plot to be 193.5-452 t/ha.

However, they also reported that the use of Bahia grass (*Paspalum notatum*) strip with 1 m width could suppress soil erosion to zero in the second and third year of experiment, whereas 0.5 m strip of Bede grass (*Brachiara decumbens*) suppressed soil erosion until zero after the fourth year of experiment.

Gintings (1982) found that the soil loss from 1-year old Robusta coffee with 59〜63% slope gradient was 1.94 t/ha which was very low compared to the soil loss from clean-weeded coffee (22.7 t/ha). 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 (Gintings, 1982), which was lower than the soil loss from clean-weeded coffee with similar age which was 9.1 and 4.8 t/ha.

The effect of coffee canopy on reducing soil loss was demonstrated clearly in Fig. 8 and Fig. 9. Table 4 showed that in clean-weeded plot, runoff was fluctuated but almost constant from the second to the fourth year of experiment. However, the soil loss tended to decrease as shown in Fig. 8. It means that although the runoff ratio was relatively unchanged after the second year, the sediment which carried by runoff became smaller year by year as shown in Fig. 9. Increasing the coffee canopy was the major factor that was responsible of these phenomena. The coffee canopy intercepted the rainfall, hence the raindrops did not directly strike the soil surface and soil aggregate did not disperse, so runoff would carry less sediment.

3. 6 Soil loss tolerance

As shown in Table 5, the soil loss from this experiment was very low ; the total soil loss from clean-weeded plot was around 4.96 mm for four years experiment or 1.24 mm per year. This value is below the soil formation rate in Indonesia, which is estimated about 2 mm per year (Shah, 1982). If we took the average soil loss only for three years observation (because the 1st experiment started too late), the average soil loss was around 12.97 t/ha or 1.35 mm/yr. This value was also lower than the soil loss tolerance for that area which was estimated between 2.5〜3.7 mm per year (Manik *et al.*, 1997) or 22.4 t/ha per year for Indonesia (Utomo, 1994).

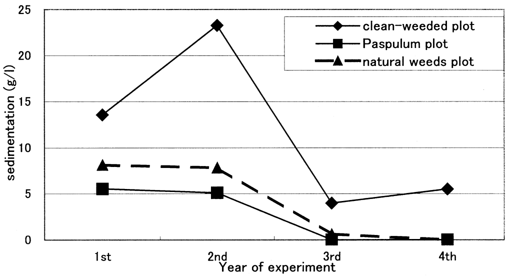

Fig. 9 Sedimentation of each plot.

Table 5 Total soil loss under coffee with different weed management

Unit (mm)

Year of observation	Clean-weeded plot	*Paspalum* plot	Natural weeds plot
1st	0.91	0.28	0.16
2nd	2.36	0.00	0.02
3rd	0.50	0.00	0.00
4th	1.19	0.00	0.07
Total	4.96	0.28	0.25
Average (mm/year)	1.24	0.07	0.06

4. Conclusion

The four years soil erosion research conducted in a hilly humid tropical area of Lampung, Indonesia, showed that only 14.2% of rainfall intensities could be categorized as the erosive intensity (>25 mm/h). The maximum rainfall intensity was 120 mm/h, and the maximum daily rainfall was 82 mm. A relationship between rainfall erosivity index (R : $t \cdot m^2$/ha/h) and daily rainfall (X : mm) was determined as follows :

$$R = 1.624\ (X - 10.9)$$

Soil loss from clean-weeded plot ranged from 4.8 t/ha to 22.7 t/ha. The total soil loss from clean-weeded plot was 4.70 mm during the four years experimental period, and 1.17

mm/year was lower than the soil formation rate in Indonesia.

The use of *Paspalum conjugatum* and natural weeds as cover crop under coffee trees was very effective in controlling soil erosion. The soil loss from *Paspalum* plot was 2.7 t/ha during the first year of experiment and became zero after the third year. However, the soil loss from natural weeds plot in the first year was 1.5 t/ha and zero after four years. Instead of weeds coverage, the reduction of soil loss after three years experiment was also caused by coffee canopy through its rainfall interception.

The presence of weeds and the increasing of coffee canopy as the coffee growth influenced the runoff significantly. *Paspalum conjugatum* could suppress runoff until zero after the third year of experiment, and in case of natural weeds it suppressed until zero after four years. Runoff in clean-weeded coffee decreased year by year due to coffee canopy growth, and runoff ratio became almost constant around 7-10% after the second year of experiment.

Both weedy plots showed the bad performance of coffee growth. However, the use of *Paspalum conjugatum* as cover crop in coffee garden was promising if managed optimally. Since *Paspalum* has a shallow roots, it competes with coffee's root, thus these species have to be introduced when the coffee trees have gained enough height (about three years old). *Paspalum* could be planted along strips between the coffee plants or around the coffee canopy.

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インドネシア・南スマトラ・ランポンの熱帯湿潤丘陵地における異なった雑草管理下のコーヒー園からの土壌侵食

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要　　旨

インドネシア・南スマトラのランポンにおいて，1996 年から 1999 年の雨季の期間，異なった雑草管理下のコーヒー園からの土壌侵食量と地表流出量を観測した。試験区は，(1)地表面の雑草を完全除草したコーヒー園，(2)被覆植物として雑草種 *Paspalum conjugatum* で地表面を被覆したコーヒー園，(3)自然植生の雑草で地表面を被覆したコーヒー園である。雑草の管理は 2 週間に 1 回の頻度で行った。試験区 (1)では地表面の雑草を完全に除去し，残りの試験区 (2)と (3)ではコーヒー樹周囲の直径 1 m の範囲を除草した。観測期間中における当地区の最大日雨量は 82 mm，最大 10 分間雨量強度は 120 mm/h であった。しかし，全降雨のうち 14.2% の最大降雨強度が，土壌侵食発生の限界となる降雨強度 25 mm/h を上回っていた。USLE 式で用いられる降雨係数 R（m^2・t/ha/h）と日雨量 X（mm）の間には，R＝1.624（X－10.9）の関係が成り立った。完全除草区の流出率は 7～15% の範囲で変化し，コーヒーの樹冠の成長にともなって減少した。雑草によって地表面を被覆すると地表流出は著しく減少し，*Paspalum* 試験区では 3 年目の雨季以降の流出率が 0% になったのに対し，自然植生の雑草試験区では 4 年目から流出率が 0% になった。土壌侵食量が最大となったのは 2 年目の雨季の完全除草区で，22.7 t /ha であった。被覆植物を導入すると土壌侵食は著しく抑制され，*Paspalum* 試験区では 3 年目以降から，自然植生の雑草試験区では 4 年目から土壌侵食が発生しなかった。完全除草区の土壌侵食量は土壌深にして 1 年間に 1.24 mm であり，インドネシアの土壌生成速度を下回っていた。

キーワード：コーヒー，土壌侵食，流出，受食性

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