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An Evaluation of Coffee Crop Factor under Different Weed Managements Using USLE Method in Hilly Humid Tropical Area of Lampung, South Sumatra, Indonesia

Afandi*, Tumiar Katarina Manik*, Bustomi Rosadi*, Muhajir Utomo*, Masateru Senge**, Tadashi Adachi*** and Yoko Oki***

* Faculty of Agriculture, University of Lampung,
Jl. Sumantri Brojonegoro 1, Bandar Lampung 35145, Indonesia
** Faculty of Agriculture, Gifu University, 1-1 Yanagido Gifu 501-1198, Japan
*** Faculty of Environmental Science and Technology, Okayama University,
3-1-1 Tsushimanaka Okayama 700-8530, Japan

Abstract

An evaluation of crop management factor (C) for coffee using USLE method was conducted in hilly humid tropical area of Lampung, Indonesia. The treatments were as follows : coffee without cover crop (clean-weeded plot) ; coffee with *Paspalum conjugatum* as cover crop (Paspalum plot) ; and coffee with natural weeds (natural weeds plot). Weed management was done every two weeks by clearing all the weeds in clean-weeded plot, and cutting the weeds around the coffee trees at a diameter of 1 m for the weedy plots (Paspalum and natural weeds plots). Two methods of estimating C-factor for coffee were used : (1) using similar condition with other crops (C_t), and (2) using equivalent method based on the existing value of coffee-C factor (C_e). The results showed that the use of C_t gave soil loss prediction 9-24 times higher than that measured, while the use of C_e gave 10-81 times higher. The predicted values of soil loss using C_t were 7.7 t/ha/year and 14.1 t/ha/year for Paspalum and natural weeds plots respectively. These values were still acceptable and reasonable to the soil loss tolerance, and very low compared to the other Indonesian studies which could be hundreds of ton/ha/y. This experiment showed that the measured coffee C-factor was 0.045 for clean-weeded plot, 0.006 for Paspalum plot and 0.004 for natural weeds plot, which were lower than the common value (0.2) usually used in Indonesia. By introducing the effect of weeds as the weeds C-subfactor (C_s) and coffee C-factor (C_b) obtained from this experiment measurement, the coffee C-factor (C_c) with various weeds coverage could be estimated by the equation $C_c = C_b\ C_s$.

Key words : soil erosion, coffee, erodibility, USLE, crop factor

1. Introduction

Of all the empirical erosion models, the USLE (Wischmeier and Smith, 1978) is the most widely used all over the world for predicting erosion loss and guide for conservation planning. However, it is often used without validating or measuring soil specific properties and rainfall factors, so the information generated can thus be erroneous, misleading, and counterproductive, which represents the misuse and abuse of empirical equation (Lal, 2000). The founding of USLE, Wischmeier (1976) has warned the misuse of USLE, such as applying C and P values from the handbook without considering, and applying the factors too broad, such as single C value for all cropland. However, Risse *et al.* (1993) showed that from

Table 1 Initial soil properties prior to planting

Depth (cm)	pH H_2O	Total-N (g/kg)	Organic-C (g/kg)	CEC (cmol/kg)	Texture (kg/kg)			Bulk density (kg/m^3)
					Sand	Silt	Clay	
0- 10	4.92	2.6	34.8	13.3	0.25	0.23	0.52	960
10- 20	4.89	1.6	18.6	9.9	0.25	0.16	0.59	930
20- 35	4.91	0.9	8.9	9.3	0.26	0.13	0.61	990
35- 60	4.87	0.7	8.2	8.7	0.26	0.13	0.61	930
60-100	4.85	0.6	8.2	8.7	0.28	0.15	0.57	—

the six parameters in USLE, the crop management and topographic factors had the most significant effect on the overall model efficiency. These indicated that most of the research emphasis should continue to be placed on these parameters.

The equation of USLE is also widely used in Indonesia as a tool for conservation planning, especially in watershed scale. Unfortunately, the results were frequently overestimated ; the value of hundreds of tons of soil loss per hectare per year predicted by USLE is very easy to be found in many literatures in Indonesia.

The above problems were arisen because it is very difficult to apply the USLE purely in Indonesia, such as how to obtain an exact value of crop management factor, especially for tree crop. Because soil erosion experiment was mainly concentrated on food crops in Java Island, there are very few Indonesian's literatures of soil erosion for some popular crops in Sumatra Island, such as coffee, sugarcane, and oil palm. The crop management factors for those tree crops are frequently estimated from the table in handbook, which are the results of experiments in the other countries with very different conditions from Indonesia. In case of coffee trees, a very limited research was done concerning soil erosion. Up till now, the values of the soil erosion from coffee trees areas were mostly predicted by USLE equation using the values from the table. So, creating a new crop factor of coffee tree from a field experiment is very important.

The objective of this study is to evaluate the value of crop management factor of coffee tree with different weeds management using USLE in a hilly tropical area of Lampung, South Sumatra, Indonesia.

2. Materials and Methods

2. 1 Study site

The study site was located at Sumber Jaya District, Lampung Province, South Sumatra, Indonesia. The study was conducted during four rainy seasons from 1995 to 1999. The slope gradient was 30% with an elevation of 780 m above sea level. The selected soil properties are shown in Table 1. The soil was classified as Inceptisols (Dystrudepts), which was dominated by clay fraction in all depths. The bulk density was very low indicating that the soil was friable and porous. The soil reaction was slightly acid with moderate cation exchange capacity. The total rainfall during four years of experimental period was 4547.6 mm, with 1136.9 mm per rainy season (usually from October to April).

2. 2 Treatment plot

The size of erosion plot was 20 m length and 5 m width (100 m^2). Two collection units were installed at the lower end of the plot for measuring soil loss. The first unit was a ditch with the capacity of 0.1 m^3, which was connected to the second unit by seven pipes. One pipe which was in the center, was connected by a siphon to a tank and the rests were overflowed to the water reservoir box in which a triangular weir and a water gauge was installed (Afandi *et al.,* 2002). The sediment and runoff water in the ditch and tank was pulled out into a drum with a siphon, thoroughly stirring the contents in the drum and quickly extracting 500 m*l* sample with plastic bottle. The total soil loss was calculated by measuring the dry weight of sediment sample and the volume of runoff water stored in the ditch and tank.

The treatments were as follows :

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

(2) **Treatment 2 (Paspalum plot)**: Coffee with *Paspalum conjugatum* as cover crop. Young *Paspalum conjugatum* was transplanted in the experiment plot in November 1995 and February 1996. *Paspalum conjugatum* is one of the weed species, gramineous perennial of 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.

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

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

2. 3 Weeds type

Sriyani *et al.* (1999) reported that a few weeds named as *Ageratum conyzoides* appeared in clean-weeded plot. Among the weeds which appeared in natural weeds plot were *Clibadia surinamense, Clidemia herta, Chromolaena odorata, Melastoma affine,* and *Imperata cylindrical*. *Clibadia surinamense* (woody species) whose mean plant height reaches 136 cm was the dominant species in natural weedy plot. *Imperata cylindrica* is a type of grass, which covered about 20% of the soil surface. Six months after the experiment started, the weeds in both weedy plots had already covered fully the soil surface.

2. 4 Methodology

(1) USLE equation

The USLE (Wischmeier and Smith, 1978), which is used as the basis of calculation, has the following formula :

$$A = R \cdot K \cdot L \cdot S \cdot C \cdot P \quad (1)$$

Where : A : soil loss per unit area per year
R : rainfall and runoff factor
K : soil erodibility factor
L : slope length factor
S : slope steepness factor
C : crop management factor
P : support practice factor

(2) Rain erosivity (R)

Rain erosivity index was calculated using the following equation of Wischmeier and Smith (1978).

$$R = E \times I_{30} \quad (2)$$

Where, R : rainfall erosivity index ($MJ \cdot mm \cdot h^{-1} \cdot ha^{-1}$)
E : total rainfall energy ($MJ \cdot ha^{-1}$)
I_{30} : the maximum 30-min rainfall intensity ($mm \cdot h^{-1}$)

(3) Erodibility factor (K)

Soil erodibility factor was calculated using the equation of Wischmeier, Johnson, and Cross (1971) as follows :

$$K = 0.132\{2.1M^{1.14}(10^{-4})(12-a) + 3.25(b-2) + 2.5(c-3)\} \quad (3)$$

where, K : erodibility factor ($t \cdot h \cdot MJ^{-1} \cdot mm^{-1}$)
M : (% silt + % fine sand) × (100 − % clay)
a : organic matter content (%)
b : the soil-structure code used in soil classification
c : the profile-permeability class

Soil structure code (b) was as follows :

(1) very fine granular, (2) fine granular, (3) medium to coarse granular, and (4) platy, blocky, or massive.

Permeability class (c) was classified as follows :

(1) rapid (>12.5 cm/hr), (2) moderate to rapid (6.25–12.5 cm/hr), (3) moderate (2.00–6.25 cm/hr), (4) slow to moderate (0.5–2.00 cm/hr), (5) slow (0.125–0.5 cm/hr), and (6) very slow (<0.125 cm/hr).

Soil samples were taken for calculating erodibility factor before rainy season. Particles size analysis was determined by sieving and hydrometer methods ; permeability was determined using falling head methods ; soil structure was determined directly in the field ; and organic matter was measured by Walkey and Black methods.

(4) Topographic factor (LS)

The topographic factor was calculated using Wischmeier and Smith (1978) equation as follows :

$$LS=(\lambda/22.1)^m(65.41\sin^2\theta+4.56\sin\theta+0.065) \quad (4)$$

where, LS : topographic factor (dimensionless)

λ : slope length (m)

θ : angle of slope

m : constant, 0.5 (percent slope>5%), 0.4 (4.5%>percent slope>3.5%), 0.3 (3%>percent slope>1%), 0.2 (percent slope<1%)

(5) Coffee and weeds coverage

a. Coffee coverage

The coverage of coffee canopy was calculated as the basis for calculating coffee C-factor.

$$A_c=3.14\times(D_c/2)^2 \quad (5)$$

$$V_c=(A_t-N\times A_c)/A_t\times100 \quad (6)$$

where, A_c : coffee canopy area (m^2)

D_c : diameter of coffee canopy (m)

V_c : coffee coverage (%)

N : number of coffee trees in experimental plot

A_t : total area of experimental plot (m^2)

The canopy diameters of coffee trees were measured every two months, and in this analysis, the average value during measurement period of each rainy season was used. The canopy diameter is one of the growth parameters of coffee trees ; hence it could be used for C-factor determination during its growth.

b. Weeds coverage

After six months of the experiment, the weeds in both weedy plots had already covered the soil surface. Before weeds management was done, the weeds spread under the canopy of the coffee. So for *Paspalum* and natural weeds plots, the following equation was used to calculate the weeds coverage (V_w) from the second to fourth year of experiment.

$$V_{wb}=100 \quad (7)$$

$$V_{wa}=(A_t-T_{aw})/A_t\times100 \quad (8)$$

$$T_{aw}=\{3.14\times(D_w/2)^2\}\times N \quad (9)$$

$$V_w=(V_{wb}+V_{wa})/2 \quad (10)$$

Where, V_{wb} : weeds coverage before cutting (%)

V_{wa} : weeds coverage after cutting (%)

D_w : diameter of weeded area around the coffee tree (m)

T_{aw} : total area, which has been weeded around the coffee tree (m^2)

V_w : average weed coverage (%)

Because the number of coffee trees in each plot (N) was 40 and the diameter of weeded area (D_w) was 1 m, so the value of V_{wa} was 69%, and average value of weeds coverage (V_w) was (100+69)/2=85%

In clean-weeded plot, a very few weeds whose heights were less than 5 cm appeared (e.g. *Ageratum conyzoides*). However, they were cleaned as soon as possible they appeared, so the weeds coverage (V_w) could be estimated to be zero.

(6) Support practice P-factor

The P-factor was derived using the value given by Wischmeier and Smith (1978). Because there was no practice management in clean-weeded plot, the P-factor was 1. The P-factor for both weedy plots was also 1, for the first year and second year of measurement. However, in the third year and fourth year of measurement, there was a change in micro slope gradient between the coffee rows along the slope due to the farmer activities such as weeds management. A single terrace between two rows of coffee trees was developed with slope gradient of 3–8%, so the P-factor for the weedy plots was 0.5 for the third and fourth year of experiment.

(7) Estimation of crop and management factor

The crop management factor was calculated based on the field condition, especially coffee and weed coverage. Because C-factor is very critical value, we use two approaches in determining the C-factor as follows.

a. C-factor derived from similar condition

The combination of ground cover (weeds coverage) and vegetative canopy (coffee coverage) was considered in determining the C-factor. Since there were no information and results about C-factor of coffee and weeds combination, the C-factor was derived from similar condition. The table given by Wischmeier and Smith (1978) for determination of C-factor for pasture, range, and idle land was matched for this purpose, because it encounters the percentage of groundcover as well as the percentage of vegetative canopy. For convenience, the C-factor derived from this table was called C_t.

b. Equivalent C-factor

Generally, the calculation of C-factor for various combinations of crops was done by weighted average methods. In this method, every single C-factor was multiplied by the proportion of the area that every crop occupied, and then the C-factor was the sum of every single C-factors. However, this method could be applied successfully if every single crop could be clearly defined separately. In case of coffee trees, this method is difficult to be applied, because the weeds and the coffee trees were located side by side from upper slope to down slope, so erosion from upper slope will be reduced and entrapped by the weeds. To encounter this problem, new equation is proposed to estimate the C-factor of weeds and coffee combination. C-factor derived from this equation was designed as C_e. The derivation of this formula is described in Appendix.

$$C_e = \{(100 - V_w)/100 \times C_c^{1/m} + V_w/100 \times C_w^{1/m}\}^m \tag{11}$$

where, C_c : single coffee crop factor

C_w : single weed crop factor

C_e : equivalent C-factor

m : constant shown in equation (4)

The coffee and weeds single C-factor used in equation (11) was derived from the research results in Indonesia. The C-factor for coffee in good coverage was 0.2 (Arsyad, 1989). Because of no information about the coffee C-factor in bad coverage, we assumed that it was similar to C-factor for rubber and tea crop with bad coverage. Those C-factor values were 0.8 for rubber and 0.5 for tea as well as mixed-garden with medium coverage (Hammer, 1981).

The weeds single C-factor for *Paspalum conjugatum* was assumed to be similar with Bede grass. There were two values of C-factor for Bede grass, 0.28 and 0.002 (Utomo, 1989). The value 0.28 was applied for the first year of experiment, because the root system of *Paspalum* as well as the coverage was not so dense, and the value of 0.002 was applied from the second year of experiment.

For natural weeds, the value 0.3 was used for the first year, assumed to be similar to shrubs (Hammer, 1981) and 0.021 from the second year which assumed to be similar to permanent alang-alang (*Imperata cylindrica*) (Utomo, 1989).

(8) Measured C-factor

The measured C-factor was calculated based on USLE equation as follows :

$$C_m = A/(R \cdot K \cdot L \cdot S \cdot P) \tag{12}$$

where, C_m : measured C-factor of each treatment

The value of C_m was calculated yearly and a single C_m factor for each treatment was found by averaging four years measurement. The value of A was obtained from the measurement in each plot ; R, K, L, S values were calculated based on the observation data, and P was taken from table based on the field conditions.

Table 2 Effects of different weeds management under coffee tree on erodibility index

Treatment	Year	silt＋very fine sand (%)	Organic matter (%)	Code structure	Code permeability	K ($t \cdot h \cdot MJ^{-1} \cdot mm^{-1}$)
Clean-weeded Plot	1st	45	3.7	4	2	0.010
	2nd	45	3.3	4	1	0.007
	3rd	45	3.3	4	1	0.007
	4th	45	3.6	4	2	0.011
	Ave		—	—	—	0.009
Paspalum Plot	1st	43	6.1	4	1	0.005
	2nd	43	4.7	4	1	0.006
	3rd	43	4.9	4	1	0.006
	4th	43	6.3	4	2	0.009
	Ave		—	—	—	0.007
Natural weeds Plot	1st	45	5.5	4	1	0.006
	2nd	45	3.0	4	1	0.008
	3rd	45	5.2	4	1	0.006
	4th	45	4.6	4	1	0.007
	Ave	—	—	—	—	0.007

Table 3 Coffee and weeds coverage

Treatment	Weeds coverage (%)				Coffee coverage (%)			
	1st	2nd	3rd	4th	1st	2nd	3rd	4th
Clean-weeded plot	19	0	0	0	1.3	23.2	100.0	92.1
Paspalum plot	26	85	85	85	1.3	5.0	7.1	20.8
Natural weeds plot	25	85	85	85	1.3	4.3	2.7	17.7

3. Results and Discussion

3. 1 Erodibility factor

The result of soil erodibility calculation is presented in Table 2.

The average value of erodibility factors for clean-weeded plot is 0.009 $t \cdot h \cdot MJ^{-1} \cdot mm^{-1}$ followed by natural weeds plot (0.007 $t \cdot h \cdot MJ^{-1} \cdot mm^{-1}$) and *Paspalum* plot (0.007 $t \cdot h \cdot MJ^{-1} \cdot mm^{-1}$). Comparing with the values of the other soils in Lampung, these values were smaller. Using the same method, Susanto (1992) found the values of erodibility between 0.024–0.052 $t \cdot h \cdot MJ^{-1} \cdot mm^{-1}$ in some Red Acid Soils (Ultisol) which were higher than the values found in this experiment due to lower permeability.

3. 2 Weeds and Coffee Coverage

The results of weeds and coffee coverage are presented in Table 3. After the second year of experimental period, the weeds in weedy plots had already covered the soil surface with an average value as much as 85% coverage. About 15% of the plots were maintained bare for coffee areas. In the case of clean-weeded plot, the weeds were cleared by hand as soon as they appeared.

In the second year, competition between weeds and coffee suppressed the coffee growth in weedy plots, so the coffee coverage in both weedy plots was around 5%, whereas in clean-weeded plot was 23%. The competition was severe in natural weeds plot due to the existence of *Clibadia surinamense* whose height could be 2 m.

In the fourth year, the coffee coverage was 21% in Paspalum plot, which means that coffee canopy covered the weeded area (about 15% of the total area) and overlapped some part of weeds area. This situation also occurred in natural weeds plot whose coffee coverage was 18%. In case of clean-weeded plot, the coffee canopy had already covered the erosion plot since the third year, and in the fourth year the coffee coverage decreased because the coffee tree had been harvested, and some of the branches were broken.

3. 3 Estimation of Crop factor

(1) C-factor derived from similar condition

In the first year, the coffee coverage was very small since there was no appreciable canopy, thus the C-factor was mainly determined by weeds coverage. The existing weeds in clean-weeded plot and Paspalum plot were in contact with the soil surface, covering about 19%-26%, so the C-factor value was 0.20. On the other hand, the natural weeds which were mostly herbaceous plants, covered about 25%, and the C-factor value was 0.24. From the second year to the fourth year, the weeds coverage in clean-weeded plot was zero, thus the C-factor was determined only by the coffee coverage. In the second year, the height of coffee tree was less than 0.91 m with coverage 23%, so the C-factor was 0.36. The C-factors for the third and fourth year were 0.28.

For Paspalum plot, the C-factor from the second to the fourth year was 0.013 because the weeds coverage reached 85% and the coffee coverage was less than 25%. So the C-factor was mainly determined by the weeds coverage. Using the same way explained above, the C-factor for natural weeds plot was 0.041 from the second to the fourth year. The value of C-factor derived from table given by Wischmeier and Smith are listed in Table 4.

(2) Equivalent C-factor method

The values of some single C-factors for coffee and weeds used in this analysis are listed in Table 5. The best C-factor for coffee with good coverage was 0.2, and the maximum value of C-factor was 0.8 for coffee with poor coverage.

Table 4 Combination C-factor (C_t) for coffee and weeds based on table given by Wischmeier and Smith (1978)

Treatment	1st	2nd	3rd	4th
Clean-weeded plot	0.20	0.36	0.28	0.28
Paspalum plot	0.20	0.013	0.013	0.013
Natural weeds plot	0.24	0.041	0.041	0.041

Table 5 Calculation of equivalent C-factor (C_e) for coffee and weeds combination

Treatment	Year	C-factor for coffee C_c	C-factor for weeds C_w	Coverage of weeds V_w (%)	Equivalent C-factor C_e
Clean-weeded Plot	1st	0.8	0.28	19	0.730
	2nd	0.5	0	0	0.500
	3rd	0.2	0	0	0.200
	4th	0.2	0	0	0.200
Paspalum Plot	1st	0.8	0.28	26	0.703
	2nd	0.5	0.002	85	0.194
	3rd	0.3	0.002	85	0.116
	4th	0.2	0.002	85	0.077
Natural weeds Plot	1st	0.8	0.3	25	0.709
	2nd	0.5	0.021	85	0.195
	3rd	0.5	0.021	85	0.195
	4th	0.2	0.021	85	0.080

Table 6 Soil losses measured and predicted by USLE

No	Year	Rain Erosivity (MJ·mm·ha^{-1}·h^{-1})	Soil loss from each treatment (ton/ha)								
			Clean-weeded plot			Paspalum plot			Natural weeds plot		
			Measurement	C_t-factor	C_e-factor	Measurement	C_t-factor	C_e-factor	Measurement	C_t-factor	C_e-factor
1	1st	3783	8.83	43.3	158.0	2.73	22.5	79.0	1.54	30.2	89.4
2	2nd	5019	22.73	73.3	101.8	0.03	2.2	33.1	0.16	8.6	41.1
3	3rd	15184	11.41	172.5	123.2	0	3.3	29.3	0.69	10.8	51.5
4	4th	9045	4.79	146.8	104.8	0	2.8	16.4	0	6.8	13.4
	Ave.		11.94	108.9	122.0	0.69	7.7	39.5	0.60	14.1	48.8

The value of 0.2 was applied if the coffee area was totally covered by coffee canopy. This value was achieved in clean-weeded plot in the third and fourth year. And in case of weedy plots, it was in the fourth year due to the fact that the weeded area (15% of total area) in both weedy plots was totally covered by coffee canopy. The maximum value 0.8 was applied when the canopy coverage of coffee was less than 25%. The results of equivalent C-factor calculated using equation (11) are presented in Table 5.

In the first year of experiment, the C-factor value was almost the same in all treatment, about 0.7. The lowest C-factor was achieved in coffee covered by *Paspalum,* 0.077 that was reached in the fourth year of experiment.

3. 4 Soil loss prediction by USLE method and soil loss measurement

Soil loss prediction using the USLE method with two values of C-factor is presented in Table 6. The average soil loss predicted by USLE using C_t was lower than using C_e. Using C_t, the average of predicted soil loss was 108.9 t/ha, 7.7 t/ha and 14.1t/ha for clean-weeded plot, Paspalum plot and natural weeds plot, respectively, and were 9–24 times higher than the measured soil loss. Using C_e, the average soil loss predicted were 122 t/ha, 39.5 t/ha and 48.8 t/ha for clean-weeded plot, Paspalum plot and natural weeds plot, respectively, which were also 10–81 times higher than that measured.

The problem related to the using of C-factor in equivalent method is the limitation of available C-factor value. For a particular crop, the value of C-factor must be constant. However, there is a big difference among values of C-factor for particular crop from hundreds of erosion plot experiments in Indonesia. For example, the range of C-factor values, 0.39 to 0.94 and 0.16 to 0.930 were found for soybean and mungbean respectively, and for alang-alang grass (*imperata cylindrica*) which relatively has the same growth performance, the C-factor ranged from 0.10 to 0.84 (Utomo, 1989).

Although the USLE estimation using C_t values at Paspalum and natural weeds plots are 11 and 24 times greater than the soil loss measurement, the predicted values are still acceptable because its average value was lower than the soil loss tolerance in Indonesia, which was 22.4 t/ha/year according to Utomo (1994) and 25–37 t/ha/year according to Manik *et al.* (1997).

The average value of the soil loss estimation using USLE in each treatment was not as high as it has been found in some Indonesian literatures. Soil loss estimation using USLE in Indonesia was usually applied on watershed scale, not in a plot scale. In Lampung, Susanto (1992) found soil loss of about 83–260 t/ha/year for rain-fed agriculture/garden in Way Kandis watershed. Alkohozie *et al.* (1992) found 354 and 314 t/ha/year for garden and rain-fed agriculture in upper Way Seputih watershed. Nugroho *et al.* (1991) found the average soil loss of 300–900 t/ha/year for upper Tulang Bawang watershed.

However, some researches in Indonesia showed that the soil loss from coffee areas was very low. Gintings (1982) reported that the soil loss from 1-year old *Robusta* coffee with 59–63% slope gradient was 1.94 t/ha (measured from May to October) and the soil loss from 3-years old coffee with slope gradient of 62–66% measured from May to October was 1.57 t/ha. Soil loss from 16-years old coffee with slope of 46–49% measured during almost one year (January-October) was 2.45 t/ha. Studies were made from December 1986 to June 1987 by Pudjiharta and Pramono (1988) under 15-yr-old coffee, corresponding results were 0.02 t/ha on a slope of 20–23% with undergrowth, and 0.12 t/ha on a slope of 4.1% without undergrowth. Gintings (1982) also found that the soil loss from virgin forest with 55–65% slope gradient in Sumber Jaya from January to October 1980 was 0.59 t/ha. Since the soil loss from coffee areas in Indonesia was very small, a little bit higher than soil loss from virgin forest areas (Gintings, 1982), the coffee C-factor should be a little bit higher than forest C-factor.

The above discussion has proved that the accuracy of soil loss prediction by USLE is mostly determined by the selection of appropriate value of C-factor. Since there was no exact information of coffee C-factor in Indonesia, approximation value using similar crop (as it was done in equivalent C-factor) or similar condition might be done with various results.

3. 5 Measured C-factor

The measured C-factor (C_m) of each treatment is shown in Table 7. The values of C_m were very low compared to the existing C-factor used in Indonesia which usually considered as 0.2. The average value of C_m in each treatment was 0.045 for coffee in clean weeded treatment, 0.006 for coffee with *Paspalum* and 0.004 for coffee in natural weeds. The coffee C-factor found in this experiment was almost same with the C-factor for *Brachiara* grass (0.02–0.002), primary forest (0.001–0.005) (Sinukaban, 1985), and undisturbed forest (0.0001–0.009) (Wischmeier and Smith, 1978). The value of 0.2 usually used in Indonesia was adopted from the values of coffee C-factor with cover crop in West Africa as compiled by Roose (1977), where the value of coffee C-factor ranged from 0.1 to 0.3. The low value of C-coffee factor found in this experiment was supported by the fact in previous discussion that the soil loss from coffee areas in Indonesia was very low. Probably, the different managements in coffee plantation had caused that the values of C-factor found in this experiment were different from C-factor values of “text book”. In Indonesia, several researchers had found the different values of C-factor for certain plant. Utomo (1989) showed that there were four C-factor values for soybean which were resulted from soil erosion plot experiment : 0.16, 0.47, 0.93, and 0.690, due to different managements. In case of coffee tree in this experiment, weeding was done by taking the weeds using hand for clean-weeded coffee. As a result, the soil was minimally destroyed, hence the soil erosion became small. In addition to this, the litter originated from the coffee leaves was never taken out from the plot.

As shown in Table 3, the percentage of weeds coverage in clean-weeded coffee plot was zero from the second until the fourth year of experiment, hence the C-factor was totally determined by the coverage of the coffee. For clean weeded coffee (as shown in Table 7), the maximum value of C_m was 0.1117 when the coffee coverage reached 23%, and the minimum value was 0.0091 when the coverage reached 92%. Since the C-value for bare soil is 1, and the minimum value of C-factor is 0.0091, a graph could be made for estimating the coffee C-value for various coffee coverage with clean-weeded management, using the measured coffee C-factors as listed in Table 7. The result is shown in Fig. 1.

The estimation of the C-factor for coffee with ground coverage could be made by introducing the concept of C-subfactor. The concept of C-subfactor which had been discussed by

Table 7 Measured C-factor

Treatment	1st	2nd	3rd	4th	Average
Clean-weeded plot	0.0408	0.1117	0.0185	0.0091	0.0450
Paspalum plot	0.0243	0.0002	0.0000	0.0000	0.0061
Natural weeds plot	0.0122	0.0008	0.0026	0.0000	0.0039

Wischmeier and Simth (1978) as well as Dissmeyer and Foster (1981) could be applied by considering the effect of weeds as the subfactor. So, the coffee C-factor (C_c) for various ground covers can be estimated as following equation :

$$C_c = C_b \times C_s \tag{13}$$

C_c : coffee C-factor with ground coverage

C_s : subfactor

C_b : coffee C-factor without ground coverage

In clean-weeded coffee, the C_c will be only influenced by C_b, so the value of subfactor C_s will be 1 or in other word the ground (weeds) coverage is 0%. On the other hand, if the ground (weeds) coverage is 100%, the C_c will be 0 because the soil loss is 0, so the C_s factor will be 0. Based on equation (13), the value of C_s subfactor in this experiment could be calculated by the following equation :

$$C_s = C_w / C_b \tag{14}$$

where, C_s : weeds C-subfactor

C_b : measuring coffee C-factor at clean-weeded plot (coffee in bare condition)

C_w : measuring coffee C-factor at both the Paspalum and natural weeds plots

Based on the values in Table 7 (C_w value), Table 3 (weeds coverage value), and Fig. 1 (C_b value), the C_s value for *Paspalum* and natural weeds could be calculated for various coverage of coffee tree using equation (14) and the results were tabulated in Table 8.

Table 8 showed that with weeds coverage of 25%, the C-subfactor was very low, less than 0.03, and the C-subfactor value was almost zero when the weeds coverage became 85%. In conclusion, applying 25% of ground coverage is enough for controlling soil loss in coffee areas, so it is not necessary for covering the whole soil surface with weeds.

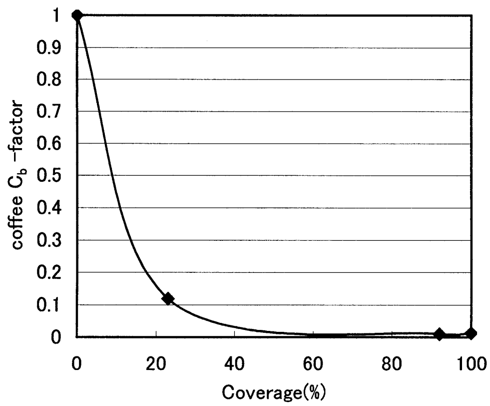

Fig. 1 Relationship between coffee C-factor (C_b) and coffee coverage.

4. Conclusion

Evaluation of coffee crop factor (C) as a part of USLE was done on erosion plot with gradient 30% in humid tropical areas of Indonesia. The coffee C-factors for USLE calculation were estimated by deriving from the available table given by Wischmeier and Smith (1978) and using new concept of equivalent C-factor. The results showed that the values of estimated coffee C-factor derived from the table were 0.013–0.28, while the values of equivalent C-factor were in the range of 0.077–0.73, and as a result, the soil loss estimated was higher when equivalent C-factor was used. Using C_t, the average soil loss was 108.9, 7.7 and 14.1 t/ha/year for clean-weeded plot, Paspalum plot and natural weeds plot respectively, which was 9–24 times greater than the soil loss measure-

Table 8 The estimated value of weed subfactor (C_s) in coffee garden

Weeds type	Year	Coverage of weeds (%)	Coverage of coffee (%)	C_c	C_b*)	C_s
Paspalum conjugatum	1	26	1.3	0.0243	0.99	0.0245
	2	85	5.0	0.0002	0.94	0.0002
	3	85	7.1	0.0000	0.60	0.0000
	4	85	20.8	0.0000	0.13	0.0000
Natural weeds	1	25	1.3	0.0122	0.99	0.0123
	2	85	4.3	0.0008	0.77	0.0010
	3	85	2.7	0.0026	0.97	0.0027
	4	85	17.7	0.0000	0.19	0.0000

*) The value of C_b is taken from Fig. 1 with each coverage of coffee tree.

ment. However, the predicted value was still acceptable and reasonable, because it was lower than the soil loss tolerance.

The measured value of coffee C-factor was 0.045, 0.006, and 0.004 for clean- weeded coffee, Paspalum plot and natural weeds plot, respectively which were lower than the value (0.2) usually used in Indonesia. By considering the effect of weeds as the subfactor (C_s), the value of coffee C-factor (C_c) with various coverage of weed can be estimated using the following equation :

$$C_c = C_b \times C_s$$

Where C_b could be estimated from the graph which was derived from this experiment.

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Appendix

Consider the equivalent C-factor of the slope as shown in Fig. 2. This slope consists of three sub-slopes where only the crop management factors are different. And soil loss from each sub-slope could be estimated by USLE equation.

Soil loss (A) is expressed in the following equation as the function of slope length (L) and

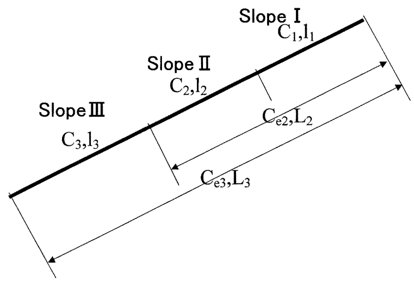

Fig. 2 Equivalent C-factor of the slope.

crop management factor (C) by combining the equations (1) and (4).

$$A=\alpha \cdot C \cdot L^m$$

$$\alpha=R \cdot K \cdot P \cdot (1/22.1)^m(65.41\sin^2\theta + 4.56\sin\theta+0.065)$$

If equivalent C-factor of slope I and II is designed as C_{e2}, soil loss from these slopes (A_2) is expressed by the following equation.

$$A_2=\alpha C_{e2}L_2{}^m$$

And soil loss from slope I (A_1) is expressed as follows.

$$A_1=\alpha \cdot C_1 \cdot l_1{}^m$$

If the slope I has the same C-factor of slope II (C_2), soil loss (A_1) is expressed by following equation.

$$A_1=\alpha \cdot C_2 \cdot l_1'^m$$

In this case, the length of slope I must be changed to l_1' calculated by the following equation.

$$l_1'=(C_1/C_2)^{1/m}l_1$$

Soil loss from slope II (A_2) is expressed by the following equation.

$$A_2=\alpha \cdot C_2 \cdot L_2'^m=\alpha \cdot C_2 \cdot (l_2+l_1')^m$$
$$=\alpha \cdot C_2\{l_2+(C_1/C_2)^{1/m}l_1\}^m$$
$$=\alpha \cdot C_{e2}L_2{}^m$$

Equivalent C-factor (C_{e2}) is expressed as follows.

$$C_{e2}=C_2\{l_2/L_2+(C_1/C_2)^{1/m}(l_1/L_2)\}^m$$
$$=\{C_2{}^{1/m}(l_2/L_2)+C_1{}^{1/m}(l_1/L_2)\}^m$$

By the same procedure, equivalent C-factor of the slope I to II (C_{e3}) can be derived as follows.

$$C_{e3}=\{C_3{}^{1/m}(l_3/L_3)+C_{e2}{}^{1/m}(L_2/L_3)\}^m$$
$$=\{C_3{}^{1/m}(l_3/L_3)+C_2{}^{1/m}(l_2/L_3)+C_1{}^{1/m}(l_1/L_3)\}^m$$

here, the coverage of the crop of slope I (V_1)

could be expressed as follows.

$$V_1 = l_1 / L_3$$

Finally, equivalent C-factor of slope I to III (C_{e3}) can be expressed by the function of single crop factor of each slope and the coverage of each crop.

$$C_{e3} = (C_3^{1/m} V_3 + C_2^{1/m} V_2 + C_1^{1/m} V_1)^m$$

異なる雑草管理下のコーヒー園における USLE 式の作物管理係数の評価

―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事例研究―

アファンディ*・ツマイア　カタリナ　マニク*・ブストミ　ロサディ*・
ムハジル　ウトモ*・千家正照**・足立忠司***・沖　陽子***
* ランポン大学農学部
** 岐阜大学農学部
*** 岡山大学環境理工学部

要　　旨

インドネシア・南スマトラ・ランポンの熱帯湿潤丘陵地のコーヒー園において，USLE 式の作物管理係数（C 値）について評価した。試験区は，⑴地表面の雑草を完全除草したコーヒー園（完全除草区），⑵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（Paspulum 区），⑶自然植生の雑草で地表面を被覆したコーヒー園（自然雑草区）である。雑草の管理は 2 週間に 1 回の頻度で行い，完全除草区では地表面の雑草を完全に除去し，Paspulum 区と自然雑草区ではコーヒー樹周囲の直径 1 m の範囲を除草した。コーヒーの作物管理係数を次の 2 種類の方法で推定した。⑴類似した植生被覆条件を有する他の作物管理係数を用いる方法（C_t）と ⑵既存のコーヒーの作物管理係数に基づいて算定した等価作物管理係数を用いる方法（C_e）である。C_t 値を用いて土壌侵食量を計算すると実測値の 9～24 倍となったのに対して，C_e を用いた土壌侵食量の予測値は実測値の 10～81 倍となった。C_t 値による土壌侵食量の予測値は Paspulum 区で 9.7 t/ha/year，自然雑草区で 14.1 t/ha/year であり，他のインドネシアの研究で予測されたコーヒー園からの土壌侵食量は数百 t/ha/年の数値が多いのに対して，これらと比較すると非常に小さな値であり，いずれも許容土壌侵食量を下回る値を示した。さらに，本実験による実測値から求めたコーヒー園の作物管理係数は，完全除草区で 0.045，Paspulum 区で 0.006，自然雑草区では 0.004 となり，いずれもインドネシアで通常用いられているコーヒーの作物管理係数の数値（0.2）よりも小さな数値を示した。実測で得られたコーヒーの作物係数（C_b）と雑草の影響を表す係数（C_s）の考え方を導入し，雑草による被覆条件下のコーヒー園における作物管理係数 C_c の算定式（$C_c = C_b \cdot C_s$）を示した。

キーワード：土壌侵食，コーヒー，耐食性，USLE 式，作物管理係数

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