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The Effect of Rainfall Intensity on Soil Erosion and Runoff for Latosol Soil in Indonesia

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ABSTRACT

Soil erosion is the most serious problem of land degradation in Indonesia. However, limited report has been documented. The erosion problem in Indonesia, particularly in Java, has been at an alarming rate. The fundamental case of soil erosion is the rain effect upon the soil. Rainfall intensity and soil characteristics are related to soil erosion and runoff. The objective of this research was to study the relationship of rainfall intensity, soil erosion and runoff in latosol soil. An experiment was conducted using plot size 22 m in length and 2 m in width and 9 % slope. A field experiment was conducted with rainfall intensity observation for 3 months, to collect soil erosion and runoff in the soil collector. A laboratory experiment was done using rainfall simulator instruments with rainfall intensity of 2.3, 3.4, 4.5, 5.6 cm/hr and 8 % slope each with 3 replications. The result of the experiments showed that soil erosion was 3.14 t/ha and runoff was 33.20 m^3/ha. When the rainfall size increased the soil erosion and runoff also increased. The correlation coefficient between EI30 (Interaction I30 and energy) and soil erosion was positive.

Key Words: Rainfall intensity, Soil erosion, Latosol soil

INTRODUCTION

Soil erosion is the removal of soil from land surface by running water (Schwab *et al.*, 1981). It is a process of soil detachment and transportation from soil agent of erosion (Arsjad, 1989). While it is generally acknowledged that erosion is serious in Indonesia, no analytical or systematic studies have been undertaken to document watershed; records of 6.0 mm/year and 1.7 mm/year were calculated from sediment concentration (Sinukaban, 1989).

Under intense tropical condition with large amount of rainfall, severe soil erosion results (Barus and Suwardjo, 1977). The situation is aggravated by the rough terrain and steep topography in the mountainous area of Java, Sumatera, Sulawesi, The Lesser Sunda Island and Irian (Sinukaban, 1989). Thus erosion damage resulting from floods occurs widespread in Indonesia (Barus and Suwardjo, 1977).

Rainfall is high during wet season, which results in increase of soil erosion (Hardjowigeno, 1989). Large area of latosol is found in Cisadane Watershed. Most of land is used for agriculture. Total critical land in Cisadane Watershed is 14733 ha and mostly situated in Bogor District (Sukartaatmadja, 1992). Intense rainfall in erosive soil, steep slopes and poor land management in Indonesia can cause serious soil erosion and water pollution (Arsjad, 1989).

Latosol soil in Indonesia is important for agriculture, but soil erosion especially in land with slopes, and high rainfall intensity tends to be high. Therefore, it need protection from soil damage (Sukartaatmadja, 1992). Research on rainfall intensity, soil erosion and runoff is needed for protection of soil from erosion damage (FAO, 1965).

The purpose of this research was to study the effect of rainfall intensity on soil erosion of latosol. The most important characteristic of soil in relation with soil erosion was erodibility . The research was to determine the value of soil erodibility.

MATERIALS AND METHODS

Plot size of 22 m x 2 m and land with 9 % slope was used for field experiment. The field experiment had a soil collector for measuring soil erosion and runoff after each precipitation. The experiment was conducted at the experiment station, Bogor Agricultural

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University, Darmaga, Bogor, Indonesia. Observation of rainfall in the location was done in 3 months.

A laboratory experiment was done to identify relationship between rainfall and soil erosion, and control for experiment in the field. The result of laboratory experiment was used to estimate field experiment. Rainfall simulator instrument with rainfall intensity 2.3, 3.4, 4.5 and 5.6 cm/hr and land slope of 8 % was used. Soil samples were taken from latosol soil at Darmaga, Bogor.

Soil sample box 30 cm in width, 59.5 cm in length and 5 cm in depth was then prepared. Soil collector was used for measurement of soil erosion and runoff. Time of experiment for each replicate was one hour. Before treatment of soil sample it was set in field capacity condition. Soil infiltration in the box of soil sample needed time and runoff was collected in the soil and water collector. Experiment of soil erosion in the laboratory used rainfall simulator with different rainfall intensity. The soil erosion was collected in soil collector and weighed in wet condition. The soil was then dried in oven. Soil particles used was below 8 mm. Soil bulk density was same condition as for field experiment (0.899 g/cm^3).

Rainfall erosivity was calculated using formula $E = 13.32 + 9.78 \log I$ and $EI = E \times I30$, and $Re = EI \times 10^{-2}$ where E= Kinetic energy of rainfall (Joule/m^2/mm), I = Total Rainfall (mm) , EI = Index of potential erosion, I30 = Rainfall intensity maximum 30 minutes (cm/hr), Re = Rainfall erosivity. Soil erodibility was calculated using formula $K = A/R \times LS \times CP$ where K = Soil erodibility, A = soil loss (ton/ha/year), R = Erosivity factor, K = Erodibility factor, LS = Slopes factor and LS= Land management factor. The rainfall was measured at Darmaga station with latitude of 60 ^{0}30$^{'}$ S, longitude of 106^{0}45$^{'}$ E, and elevation of 250 m.

RESULTS AND DISCUSION

Precipitation and Erosivity

Mean of precipitation at Darmaga was 294.1 mm per month. The highest monthly precipitation was in November, while the lowest monthly precipitation was in July. Monthly precipitation at Darmaga station from 1964 to 1998 is shown in Figure 1.

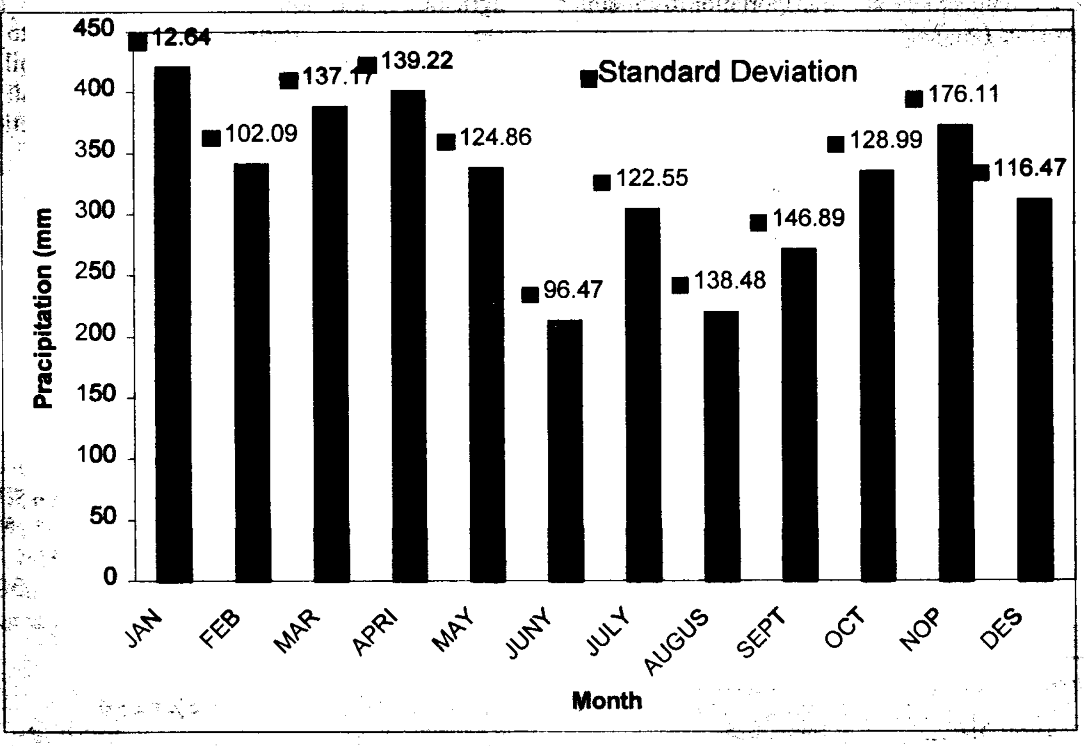

Figure 1. Monthly precipitation from 1964 to 1998 at Darmaga Station

Distribution of precipitation at Darmaga station from 1964 to 1998 is in normal condition. Wet season in Bogor area is from September to April, while dry season is from May to August (Barus and Suwardjo, 1977). Average yearly precipitation of Darmaga station from 1964 to 1968 was 3810 mm. Yearly precipitation distribution of Darmaga station shows a minimum of 2810 mm and a maximum of 5048 mm. The yearly precipitation of Darmaga station in shown in Figure 2.

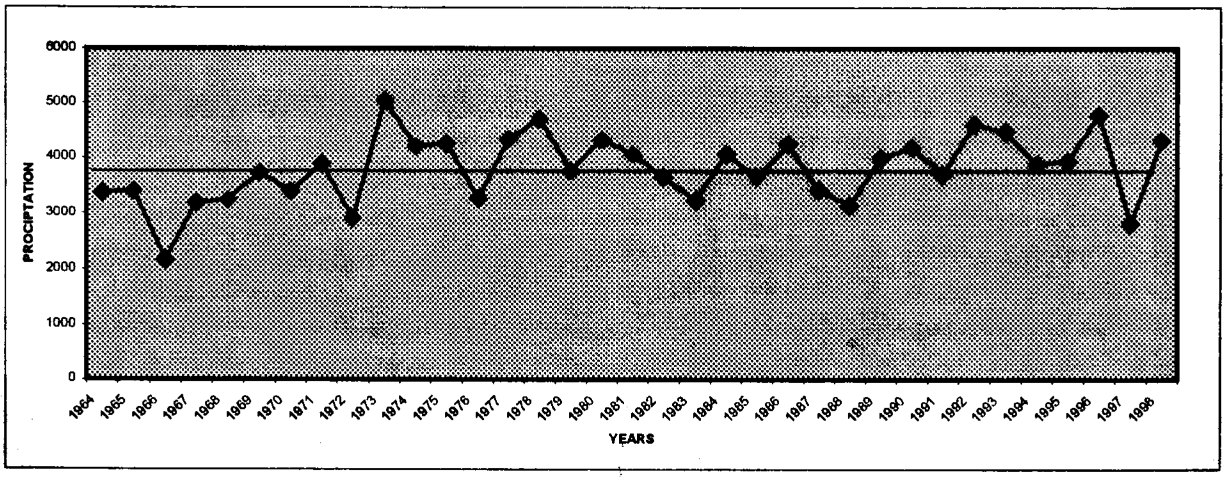

Figure 2. Yearly precipitation of Darmaga station, 1964 to 1998

Maximum rainfall intensity of 30 minutes (I30) is closely related with soil erosion and it is an important variable (Barus and Suwardjo, 1977). Monthly maximum rainfall intensity from 1980 to 1989 ranges from 2.6 to 4.9 cm/hr. The highest I30 value is in October and the lowest is in January. Interaction between energy and rainfall intensity (EI30), calculated from total kinetic energy and I30 is important for soil erosion research (Wischmeier and Smith, 1978). I30 and EI30 at Darmaga station are shown in Figure 3. Indeed EI30 is important for research in soil erosion and runoff (Wischmeier and Smith, 1978)). Tropical rains are more erosive than temperate rains, because of the high intensity of tropical storms. Tropical storms are generally accompanied by high intensity winds that further increase their aggressiveness. The kinetic energy of a storm is affected by rainfall intensity; drop size distribution and terminal velocity (Sinukaban, 1989).

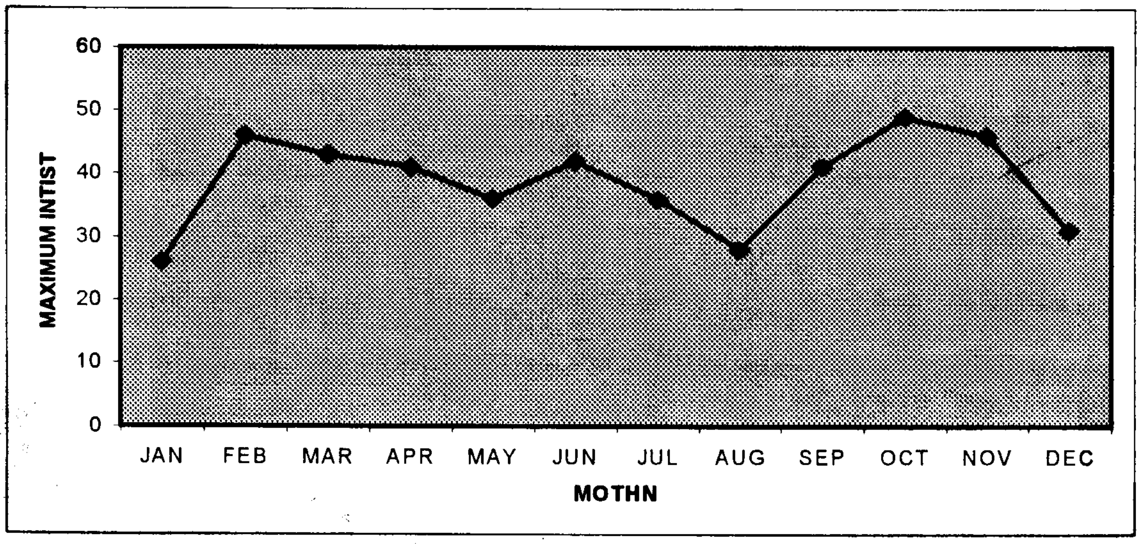

Figure 3. I30 at Darmaga station, 1980-1989

Table 1. Rainfall during field experiment, August to October 1990.

Date	Rainfall (mm)	I30 (cm/hr)	EI30 (Joule/m^2/mm)
Aug 21	29.5	2.9	80.3
Aug 25	24.5	3.0	80.8
Aug 30	23.0	1.9	50.6
Sep 1	30.0	5.0	138.8
Sep 7	62,5	6.0	185.3
Sep 10	30.5	4.8	133.6
Sep 14	21.0	3.8	99.7
Sep 22	87.0	4.0	129.1
Sep 23	17.0	3.2	81.1
Oct 13	43.0	5.8	169.9
Oct 22	67.5	8.8	274.6
Oct 30	57.0	7.8	237.8
Oct 31	104.0	12.2	403.1

Field experiment starts from August to October 1990. The precipitation at field experiment during experiment is shown in Table 1. Total rainfall in August is 77 mm, in September was 248 mm and in October was 271.5 mm. Compared to mean rainfall from 1964 to 1998, they were not different significantly. The rainfall at the time of experiment was considered normal condition. The lowest value of EI30 was 50.6 and the highest value was 403.1 joule/m^2/mm. Rainfall intensity, total rainfall and kinetic energy were potential for soil dispersion and runoff (Arsjad, 1989). Increase of EI30 caused soil erosion to increase, whereas EI30 was highly related to soil erosion. Therefore, EI30 was an important variable for research in soil erosion and runoff (Wischmeier and Smith, 1978). The lowest daily rainfall value was of 17.0 mm and the highest was 104.0 mm. The value of daily rainfall was important in identification of soil erosion. In tropical country, EI30, kinetic energy and calculated of EI30 can be used for soil erosion research (Barus and Suwardjo, 1977). The principle characteristics of rains that affected runoff and erosion were intensity and duration, distribution of rainfall intensity throughout the storm, frequency of occurrence, and seasonal and area distribution (Hudson, 1981).

Soil type, Physic and Organic matter

Erosion and limited soil conservation is serious problems in upland area. In general, land in upper Cisadane Watershed was used for paddy field (18.2%), estate crop (16%), upland and mix farming land (34.9%), forest area (21.6%), urban area (4.2 %), bushes area (4.4%) and others (0.7%). The soil types in upper Cisadane Watershed area consisted of andosol soil, regosol soil, alluvial soil and podsolic oil. Latosol soil in upper Cisadane Watershed covered 73% of the total area (Sukartaatmadja,1992). Latosol soil has flat slope until steep area with upland and estate crops. Therefore, latosol soil is an important soil resource in Bogor area. Soil type distribution in upper Cisadane Watershed is shown in Table 3.

Table 3. Soil type distribution in upper Cisadane Watershed.

No.	Soil type	Total area (Ha)	Percent
1	Andosol	4 271.50	4.6
2	Latosol	68 103.00	73.0
3	Regosol	3 471.00	3.7
4	Alluvial	13 608.00	14.7
5	Podsolik	1 708.50	1.8
6	Hidromorf	2 123.80	2.2

Soil physic and organic matter have relation to soil erosion and runoff. Each soil type characteristics needs soil analysis (Arsjad.1989). The soil characteristic of latosol has low bulk density and texture clay loam with low organic matter (Table 4).

Table 4. Soil physic and organic matter from field experiment.

Soil physic and soil organic matter	Mean
Bulk density (depth of soil 0-15 cm) (g/cm^3)	0.899
Texture (%)	
Clay	70.715
Loam	23.740
Sand	5.545
Organic Matter (%)	
C	1.860
N	0.195
C/N	9.500

Soil bulk density of field experiment 0.899 g/cm^3 indicated comparison between soil dry weights with soil volume. An increase of soil bulk density caused condition of soil compaction and related with infiltration and root growth. The value of soil bulk density lower than 1 caused easy water to flow through the soil (Hardjowigeno, 1989).

Soil texture of field experiment was clay loam. With 40% – 60% clay, the soil was very sensitive to soil erosion. The stability of soil depends on clay mineral (Morgan, 1979). The soil was not good as indicated by organic matter in the soil lower than 10%. Soil erosion and runoff could decrease soil organic matter (Millar and Turk, 1986). High organic matter and soil clay increased capacity of cation exchange. (Hardjowigeno, 1989).

The result of measurement on soil infiltration was :

$Ic = 1.241\ t^{0.17}$ $\qquad Ir = 12.65\ t^{-1.83}$

Where Ic = Infiltration accumulation (cm)

Ic = Rate of infiltration (cm/hr)

T = time (minute)

Runoff and Soil erosion

Runoff and soil erosion were measured after rainfall in soil collector. Runoff and soil erosion from field experiment for 3 months observation is shown in Table 5.

Table 5. Runoff and Soil erosion from field experiment in 1990.

Date	Runoff (m^3/ha)	Soil erosion (kg/ha)
Aug 21	0.540	0.250
Aug 25	1.077	0.472
Aug 30	2.729	29.613
Sep 1	4.531	78.204
Sep 7	7.261	565.840
Sep 10	9.106	226.659
Sep 14	0.756	0.863
Sep 22	11.111	1594.045
Sep 23	0.970	53.522
Oct 13	16.489	3167.341
Oct 22	55.927	581.750
Oct 30	58.927	5501.364
Oct 31	94.822	8118.273

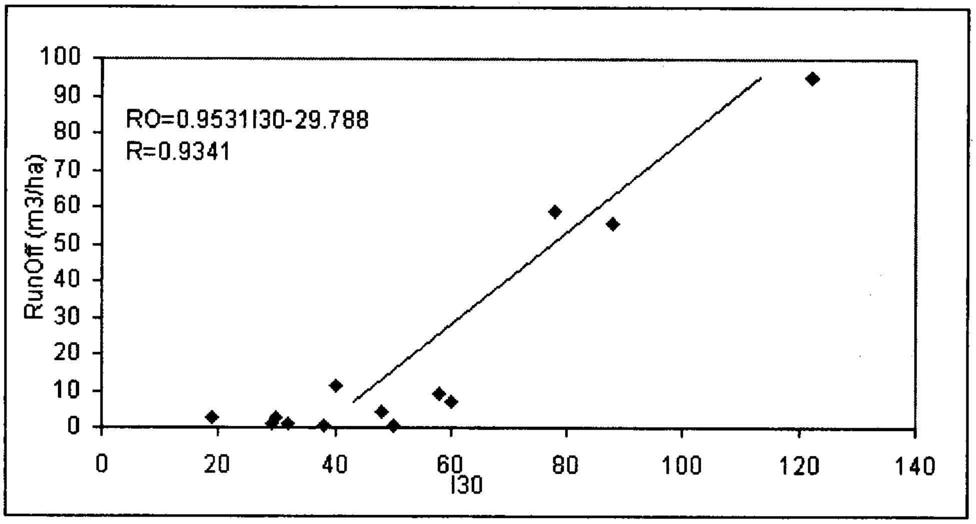

Figure 4. Relation between I30 and runoff from field experiment

The lowest runoff from field experiment is 0.540 m^3/ha and the highest is 94.792 m^3/ha. Runoff occurred after sufficient water infiltration. Runoff influenced soil erosion. Relation of rainfall intensity 30 minutes (I30) and runoff is shown in Figure 4. Runoff depended on I30 because rainfall intensity 30 minutes increased runoff (Morgan, 1979).

The result of soil erosion from each rainfall was different. The value ranged from 1.1 g/44 m^2 with rainfall intensity of 29 mm/hr to 36720.4 g/44 m^2 with rainfall intensity of 122 m/hr. Rainfall intensity, kinetic energy and interaction between I30 and energy (EI30) were parameters that have relation with soil erosion. Total soil erosion of 3 months observation was 24.99 t/ha. The relation between I30 and soil erosion in field experiment is shown in Figure 5.

The rainfall from August to October was normal but was not the maximum in the wet season. Soil erosion was higher in the wet season. If it is higher than 12.3 t/ha/year, it will have detrimental to land resources (FAO, 1965). Observation of soil erodibility in the field experiment with soil erosion and rainfall erosivity gave a value of 0.017. This factor indicated that soil in the field experiment was not very sensitive with soil erosion. Clay soil texture from field experiment with slope related to the increase of soil erosion.

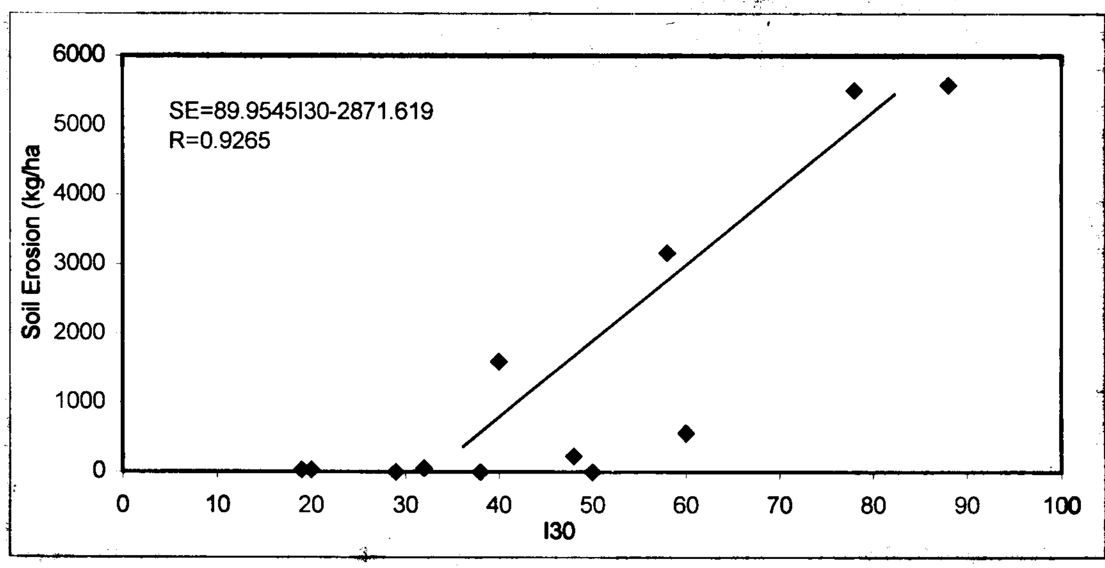

Figure 5. Relation between I30 and soil erosion from field experiment

Table 6. Runoff from rainfall simulator (m3/ha).

Rainfall intensity (cm/hr)	Land slope (%)	Replicates			Mean
		1	2	3	
2.3	8	1.01	1.39	1.33	1.22
3.4	8	23.98	26.38	25.32	25.21
3.5	8	52.99	58.46	55.45	55.61
5.6	8	172.93	193.01	182.97	182.97

Total of soil sample 12

The result of runoff from rainfall simulator instrument is shown in Table 6. Each experiment was run for 1 hour. The same land slope and rainfall intensity with the field experiment were measured by rain gauge instrument. The increase of rainfall intensity increased amount of runoff. Excess of rainfall after evaporation and infiltration was important for water resources (Arsjad, 1989).

The lowest runoff 1.22 ml/1785 cm^2 was observed with rainfall intensity of 2.3 cm/hr. Soil in sample box has bulk density nearly same in the field experiment. The result of runoff value, was affected not only by rainfall, but also by soil characteristic. In laboratory experiment even, soil under disturbances soil the rainfall has effect on runoff. Runoff influenced soil texture and soil erodibility (Schwab *et al.*, 1981). Runoff from latosol soil was higher than regosol soil, because of their different soil characteristics. Trend of increasing runoff with rainfall intensity was the same in podzolic soil. The result in podzolic soil showed that increasing rainfall intensity caused runoff to increase (Sukartaatmadja, 1983).

Table 6. Runoff from rainfall simulator (m3/ha).

Rainfall intensity (cm/hr)	Land slope (%)	Replicates			Mean
		1	2	3	
2.3	8	113.20	169.80	226.40	169.80
3.4	8	1528.20	1245.20	1358.40	1377.23
3.5	8	2773.40	2264.00	2773.40	2603.60
5.6	8	4131.80	4188.40	5207.20	4509.13

Total of soil sample 12

The result of soil erosion from rainfall simulator is shown in Table 7. Mean of soil erosion with rainfall intensity of 2.3 cm/hr was 3.0 g/1785 cm^2. With the increase of rainfall intensity, mean of soil erosion also increased. Runoff also increased. It means that soil erosion also depends on rainfall intensity. Soil particle erodes after dispersion by rainfall energy and transportation by runoff (Hudson, 1981).

Soil texture is a function of soil erosion occurrences. Soil dispersion increases with the increase of soil particle. However, an increase of transportation is related to decrease of soil particle size. Therefore latosol soil with clay texture is difficult to disperse compared to sand texture (Morgan, 1979). Soil with clay texture is easily suspended by rainfall, soil compacted, and runoff increased. Soil erosion has relation with EI30 and it is shown in Figure 5 Effect of increase EI30 to soil erosion was positive. Soil erosion can be predicted with EI30.

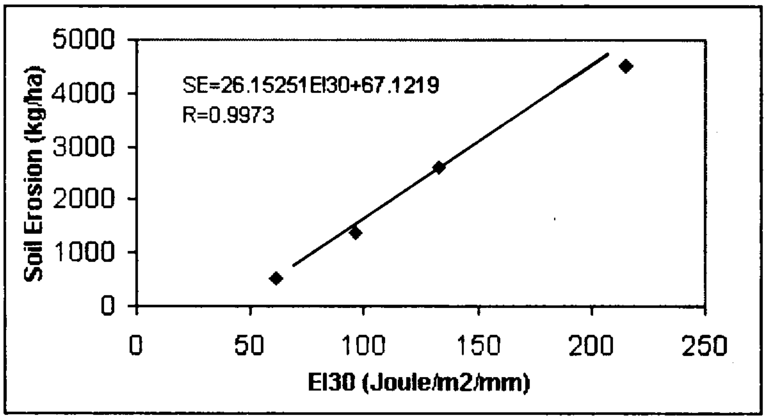

Figure 6. Relation between soil erosion and EI30 from laboratory experiment

Discussion

The rainfall has a power for soil detachment. This power is higher than runoff for transportation. Therefore rainfall has a potential function for soil erosion. (Hardjowigeno, 1989). Relation between rainfall intensity and kinetic energy is apparent.

$E = 13.32 + 9.78 \log I$

and

$Re = EI30 / 100$

Where : E = Kinetic Energy (joule/m^2/mm)

I = Total rainfall (mm)

I30 = Rainfall intensity maximum 30 minutes (cm/hr)

Re = Rainfall Erosivity

Field experiment and laboratory experiment has the same trend of soil erosion and runoff. The condition of soil depth in the laboratory experiment caused runoff more higher runoff. However, no different was observed for soil erosion. Rainfall erosivity (Re) is a parameter for estimating soil erosion (Wischmeier and Smith, 1978). Rainfall intensity, runoff and soil erosion from this experiment was positively correlated. A coefficient of correlation higher than 0.80 was found. Lembaga Penelitian Tanah reported relation of rainfall with soil erosion. The rainfall parameter was used for estimating soil erosion. EI30 have good parameter for estimating soil erosion and runoff and also have higher coefficient of correlation.. In tropical country like Indonesia, soil erosion by water caused soil degradation. Soil erosion is disadvantageous for agriculture land. Rainfall intensity has a function for identifying relation to soil erosion. From the rainfall figure it can be learned about rainfall intensity, total rainfall, kinetic energy and its relation to soil erosion (Barus and Suwardjo, 1977).

Soil erodibilitity (K) from this research was 0.017. It means total soil loss every year per unit of index soil erosion rainfall from land without crop (bare soil), without soil conservation, 9 % of land slope and 22 m length. Soil texture, organic matter, soil structure and soil permeability are influenced by soil erodibility. Latosol soil has the lowest K than podzolic, regosol and grumosol soil. However, land slope, vegetation, land use in upper Cisadane Watershed may contribute for high soil erosion.

From the experiments, it can be concluded

1. Mean of runoff and soil erosion on latosol soil were 33.20 m^3/ha and 3.14 t/ha respectively. Increase of rainfall intensity increased runoff. Soil erodibility (K) from latosol soil was 0.017.
2. The equation of relation between EI30 and soil erosion is as follows :

   $S.E = 26.152\ EI\ 30 - 67.1219$

   $R = 0.9973$

   Where : S.E = Soil Erosion (kg/ha)

   EI 30 = Interaction between I30 and energy (Joule/m^2/mm)

   R^2 = Coefficient correlation
3. The rainfall in Bogor area is high. Runoff and soil erosion will also be high. Therefore, latosol soil needs conservation. Upland in upper Cisadane Watershed (73% of which is latosol soil) has a high priority for soil conservation program.
4. The equation of accumulative infiltration and rate of infiltration are:

   $Ic = 1.24\ t^{0.17}$ and $Ir = 12.65\ t^{-1.83}$

   Where : Ic = infiltration accumulation (cm)

   Ir = Rate of infiltration (cm/hr)

   t = time (minute)

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