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RUNOFF AND SOIL LOSS FROM EROSION PLOTS IN IFE AREA OF SOUTHWESTERN NIGERIA

Ruissellement et mesure de l'érosion du sol dans des parcelles expérimentales de la région d'Ife (SW Nigeria)

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RESUME

L'érosion par ruissellement diffus a été étudiée dans trois parcelles contiguës de 1980 à 1982 en vue d'examiner les effets de la couverture végétale et de l'utilisation du sol et de déterminer les paramètres d'érosivité les plus importants contrôlant les pertes de sol de trois parcelles expérimentales installées sur sol nu (A), sur sol planté de maïs (B) et sous forêt secondaire dégradée (C).

Ruissellement et érosion sont beaucoup plus élevés sur le sol nu que sur le champ de maïs et surtout que sous la forêt. Pour la période étudiée, les pertes en sol se montent respectivement à 157 kg, 93,8 et 78,9 kg ha^{-1} an^{-1}.

Comme il fallait s'y attendre, les pertes de sol sont corrélées significativement avec le ruissellement sur toutes les parcelles. Vient ensuite pour la parcelle nue, l'intensité maximum de la pluie puis les coefficients EI_{30}, EI_{15}, $KE>25$ et AI_{15}. Dans le champ de maïs et sous la forêt, l'ordre des corrélations est le suivant : lame d'eau précipitée, intensité maximum, AI_{15} puis $KE>25$ et EI_{30} pour l'un, EI_{15}, EI_{30} et $KE>25$ pour l'autre.

L'analyse en régression multiple pas à pas montre que le ruissellement seul est responsable de 83, 76 et 53 % des variations dans la perte de sol sur les parcelles A, B et C respectivement. Ces valeurs deviennent 86, 81 et 70 % quand on prend en considération l'ensemble des paramètres de l'érosivité.

Cette étude confirme le faible pouvoir érosif du splash agissant seul sans l'aide du ruissellement.

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ABSTRACT

Runoff and soil loss were studied from three contiguous erosion plots between 1980 and 1982 in order to examine the effects of different landuse/vegetal cover on runoff and soil loss, and to determine the most important erosivity parameters relative to soil loss from the erosion plots, one of which was left bare (A), the second repeatedly cultivated to maize (B), while the third was left under a degraded secondary forest (C).

Runoff and soil loss were consistently highest from the bare plot followed distantly by the maize and forest plots. For the study period, soil loss averaged 157.8 kg/ha/yr, 93.8 kg/ha/yr and 78.9 kg/ha/yr from plots A, B and C respectively, most of which were generated during few high intensity storms.

As expected, soil loss correlates most significantly with runoff on all the plots, followed in the bare plot by rainfall peak intensity, rainfall amount, EI_{30}, EI_{15}, *KE>25 and the* AI_{15} *indices. In the maize plot, runoff is followed in order of importance by rainfall amount, peak intensity,* AI_{15}, *KE>25 and* EI_{30} *indices. In the forest plot, runoff is followed in order of importance by rainfall amount, peak intensity,* AI_{15}, EI_{15}, EI_{30} *and KE>25 indices.*

Stepwise multiple regression analysis shows that runoff alone accounts for 83 %, 76 % and 53 % of soil loss variances from plots A, B, and C respectively. All the erosivity parameters examined in the study explain a total of 86 %, 81 % and 70 % variation in soil loss from plots A, B and C respectively. This essentially shows that while rain drop impact may be very important in soil detachment, without a transporting agent it may be incapable of causing significant downslope sediment movement.

INTRODUCTION

Soil erosion by water on a slope is a sequential process of soil detachment and transport by rain-drops and runoff. Rain-drop erosion involves the detachment of particles from exposed soils on impact and their movement by splashing, while runoff erosion is caused by turbulent overland flow. Of the two, rain-splash appears to be more important (see for instance ELLISON, 1944, 1947, 1952; BORST & WOODBURN, 1942; YOUNG & WIERSMA, 1973; ROOSE, 1975; MORGAN, 1978). The energy required depends primarily on the kinetic energy per unit of rain which is directly related to its drop size and is roughly proportional to rainfall intensity (WISCHMEIER & SMITH, 1958). However, the amount of sediment generated by an individual rain-storm is also a function of other factors among which are soil erodibility, the slope of the land, the topographic position and local relief as well as the density of vegetal cover.

A distinction is generally made between geologic and accelerated soil erosion. The former involves slow removal of the soil by the various denudational agents while the latter entails the removal of soil much faster than it can be formed (STRAHLER, 1973). Accelerated soil erosion can readily occur where the vegetation has been recklessly destroyed by man through overcultivation, overgrazing, careless engineering projects and possibly through some natural events.

Study objective

Accelerated soil erosion is an endemic problem in the humid tropics especially in Nigeria, yet little is known of the dynamics. Researchers on accelerated soil erosion among others emphasized factors such as high population density and the attendant pressure on the land, the nature of the local geology, the physical and chemical properties of the soils and rainfall amount (GROVE, 1952; OFOMATA, 1965; FLOYD, 1965). No attention has been paid to the dynamic interaction between factors of soils erodibility and rainfall erosivity in relation to the rate of sediment production from under different vegetal cover and from different land uses. Thus efforts at solving the problems of soil erosion in the country have met with little success. However, experimental studies of soil erosion based on erosion plots and data on rainfall erosivity parameters are now being attempted, but the efforts are few and far between e.g. (KOWAL, 1970; LAL, 1974; JEJE, 1977; LEOW & OLOGE, 1981). Thus this study which covered the period from 1980 to 1982 is a further contribution to the attempts at a detailed study of soil erosion processes based on experimental plots in this part of south-western Nigeria. The study will focus on :

(i) the effects of different landuse/vegetal cover on sediment yield,

(ii) the influence of various factors of rainfall erosivity on soil loss in order to determine the most important factors of sediment yield with particular regard to vegetal cover, rainfall and runoff parameters.

Rainfall parameters studied

Rainfall erosivity involves energy expenditure for breaking down and splashing soil particles as well as their entrainment in an overland flow. The critical properties of rainfall erosivity such as duration, intensity, amount, drop size, mass and terminal velocity subsumed under kinetic energy have been studied and their relationship to soil loss examined by LAWS & PARSONS (1943); GUNN & KINZER (1949); BUBENZER & JONES (1971); ELLISON (1947); BISAL (1960); HUDSON (1965); LAL (1974); JEJE (19/7) among others. Intensity appears to be the most important rainfall parameter as it relates to other rainfall parameters as well as to soil loss (MOORKEJEE, 1950; WISCHMEIER & SMITH, 1958). Using the published data on drop size distribution and terminal velocities by LAWS & PARSONS (1943), WISCHMEIER & SMITH (1958) determined the kinetic energy of rainfall as follows :

$$KE = 13.32 + 9.78 \log I \qquad \text{(i)}$$

where KE = kinetic energy in Joules m^{-2} mm^{-1}

I = rainfall intensity in mm hr^{-1}

For high intensity tropical rainfall, HUDSON (1965) derived the equation :

$$KE = 29.8 - 127.5/I \qquad \text{(ii)}$$

Several parameters of kinetic energy in relationship to soil loss have been examined by various workers. Thus WISCHMEIER & SMITH (1958, 1962) in the U.S., and STOCKING & ELWELL (1973) in Rhodesia (Zimbabwe) found the EI_{30} index to be the best predictor of soil loss from bare surfaces. However, HUDSON (1971), and AHMAD & BRECKNER (1974) found low correlations between the EI_{30} index and soil loss in Tobago. Also, HUDSON (1971) found the total kinetic energy of rainfall intensity greater than 25 mm hr^{-1} i.e. KE>25 to be a more significant predictor of soil loss in Rhodesia than the EI_{30} index. HUDSON thus established the KE>25 index as the intensity threshold at which soil erosion by rain starts. After reworking HUDSON's index, STOCKING & ELWELL (1973) concluded that while the EI_{30} index best predicts soil loss from bare soils, the EI_{15} and EI_5 indices relate best to soil loss from surfaces with sparse and dense vegetal covers respectively.

Based on experiments at the International Institue of Tropical Agriculture (I.I.T.A.), LAL (1976) proposed that the AI_m which is the product of total rainfall amount (A) and peak intensity (Im) best predicts soil loss from Alfisols in southwestern Nigeria on standard, non-vegetated runoff plots on slopes of 1, 5, 10 and 15 percent. According to LAL (1976), with an r-value of 0.81, the AI_m index proved to be more significant than the EI_{30} at 0.75, but it is more or less of the same significance as the KE>25 at 0.80.

However, based on a study from erosion plots in the University of Ife, JEJE (1977) found that runoff more than any other erosivity factor correlates more with soil loss on sparsely cropped plots on 8 per cent slopes; while runoff, rainfall amount and the EI_{30} index appear to correlate more with soil loss on sparsely cropped plots on 4 per cent slopes.

All the above indices of rainfall energy, i.e. EI_{30}, EI_{15}, KE>25, AI_{15} together with the mean and peak intensities, total rainfall and antecedant moisture condition are examined in relationship to soil loss in this study. The last parameter is especially important as it has a strong bearing on runoff and erosion (BRIDGES & HARDING, 1971; BARNES & FRANKLIN, 1970). The EI_{30}, EI_{15}, KE>25 and AI_{15} indices were computed only for rainfall in excess of 12.5 mm. The EI_5 or the AI_5 indices were not computed due to the coarseness of the raingauge charts used on which only the 15 minute interval can be clearly discerned.

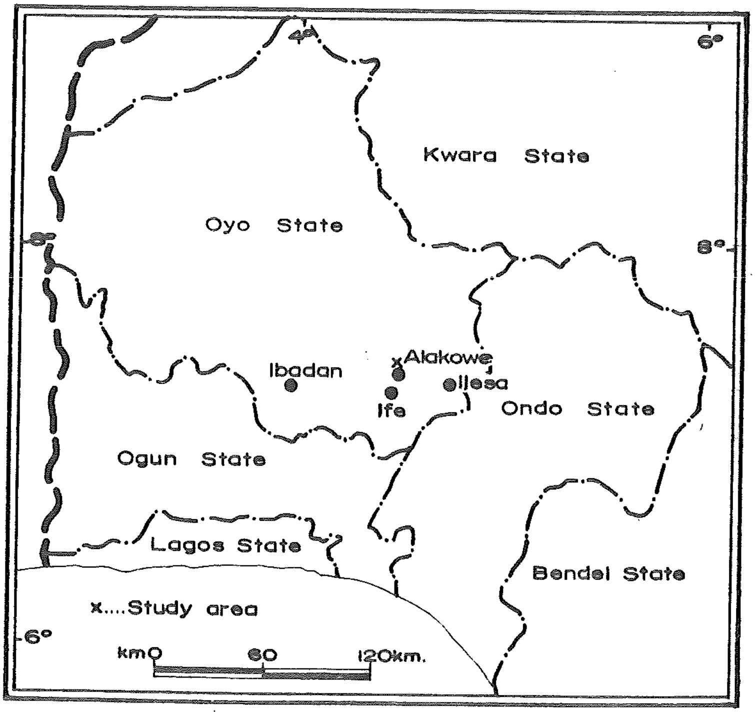

Fig. 1 : Location of Ife area.

Study area

The erosion plots were located on a 1st order valley side on a 10 % slope in the basin of Opa river close to Alakowe village some 16 km by road from the University of Ife Campus (Fig. 1). The slope is convexo-rectilinear-concave in profile. The break of slope between the upper convexity and the rectilinear segment is marked by a continuous outcrop of ferruginous crust. The plots were located on the rectilinear slope segment.

The site is underlain by the Egbeda soil series developed on deeply weathered, fine grained biotite- gneisses and schists.

Ife area is in southwestern Nigeria characterized by humid tropical climate (Am of Koppen climatic classification) with a mean annual temperature of 27° C and a mean annual rainfall of 1400 mm experienced from March to October with double peaks in July and September, and a short dry spell in August. The onset and withdrawal of the rains are marked by thunderstorms accompanied by high rainfall intensity.

Study method

The data for this study were generated from three contiguous erosion plots and from two automatic tilting rain-gauges located close to the erosion plots. A manual rain-gauge was installed in the station to act as a check on the accuracy of the automatic rain-gauges. The plots which each measured 4 m by 25 m were designated A, B, and C. Plot A was kept bare all the time, B was repeatedly planted to maize at about 8100 stands per hectare during the early rains and about 6200 stands per hectare during the late maize. During the early rains, the rows were 1 m apart, and along each row, the stands were 1.25 m apart, while during the late rains, the rows were 1.3 m apart and along each row, the stands were 1.25 m apart. The plot was mulched, being covered with maize stovers from previous seasons and with refuse manually weeded inside it. Plot C was located in a degraded secondary forest regrowth comprising three layers; the tallest are emergents up to 25 m high with canopies far apart, the middle layer 10-15 m high have rather discontinuous and irregular canopy while the third layer comprised scattered saplings and shrubs generally less than 5 m high. The forest floor is well opened. As the litter layer was very sparse, a significant proportion of the soil surface was exposed.

Runoff from each plot was obtained from collecting tanks and measured, after which it was stirred vigorously and samples taken for laboratory analysis to determine suspended and solute loads using filtration methods.

Rainfall parameters such as EI_{30}, EI_{15}, KE>25 and AI_{15} were determined from data derived from the automatic rain-gauges, and analysed following the methods outlined by MORGAN (1979). Rainfall amount, and peak intensity (for 15 minutes) were obtained directly from the rainfall charts while antecedent precipitation index was determined following GREGORY & WALLING's (1975) modification of BUTLER's (1957) method :

$$Pa = Pt.1/t \quad \text{or } Pt.K^t \qquad \text{(iii)}$$

where Pa = antecedent precipitation index (A.P.I.)

Pt = precipitation for any given day

t = time elapsed in number of days after the rainfall

K = recession factor which is less than 1.0, but ranging from 0.85 to 0.98. The smaller figure was used in this study.

The total amount of sediment load measured from each plot was taken to represent the dependent variable (Y), and the selected rainfall parameters were related to it, first, in a pairwise correlation, and then by means of a stepwise multiple regression of the form :

$$Y = a_0 + a_1 x_1 + a_2 x_2 + \ldots a_n x_n \qquad \text{(iv)}$$

in order to assess which of the rainfall parameters is the best predictor of sediment yield from the erosion plots.

RESULTS

Soil characteristics

Table I indicates some of the physical characteristics of the soils in the study area.

The upper few centimeter is dark grey to dark greyish brown, loose, clayed fine sand to very clayey fine sand with weak crumb structure to structureless, it has a fairly low concentration of quartz gravel and concretions. At a depth of about 50 cm, it is very clayey sand with frequent quartz gravel and stones. The soil is relatively deep and well drained. However with the high relative concentration of silt, and the low organic matter content along with its poor structure, the top soil down to 50 cm appears highly erodible (RICHTER & NEGENDANK, 1977).

Soil depth cm	Texture class	% Gravel and concretions >2000 µm	% sand >2000 µm	% silt >50 µm	% clay <2 µm	Bulk density	% Organic matter
0-50	Clay-loam	13.7	35.2	32.6	32.2	1.30	3.47
50-90	Sandy-clay	47.8	50.4	5.4	44.2	1.24	0.57
90-120	Sandy-clay loam	15.6	67.8	4.0	28.2	1.43	-
120-150	Sandy-clay loam	18.6	58.4	14.5	26.1	1.25	-

Tab. I : Physical properties of the soil in the study area. n = 10.

Rainfall and runoff

Rainfall amount varies from year to year with the highest of 1417 mm in 1980 and the lowest of 924 mm in 1982. The rainfall peak intensity corresponds fairly with the rainfall pattern. May recorded the highest mean intensity followed by October - at the onset and withdrawal of the rainy season respectively. High intensity storms were few from June to September when only very few rain storms exceeded 60 mm hr^{-1} intensity. Generally storms with mean intensities less than 10 mm hr^{-1} were dominant (38 %) of all recorded rainstorms, followed by 10-20 mm hr^{-1} mean intensity storms (7 %), 20-30 mm hr^{-1} (20 %), 30-40 mm hr^{-1} (20 %), 40-50 mm hr^{-1} (4 %), 50-60 mm hr^{-1} (4 %), 60-80 mm hr^{-1} (3 %), 70-80 mm hr^{-1} (3 %) and 90 mm hr^{-1} (1 %).

About 92 % of the entire rainfalls generated runoff, but the thresholds rainfall amount that generated any runoff varied from month to month depending on the frequency and amount of the antecedent rainfall. For instance in 1982 where in the relatively dry month of April, the threshold rainfall was 7 mm this declined to 5.4 mm in June and 2.5 mm in July rising to 6.5 mm in the relatively dry month of August, and declining to 2.5 mm in October.

As expected, runoff was consistently higher from the bare plot (A) than from the others, and this was followed by plot B (Tab. II). Plot C under the degraded secondary forest produced the lowest runoff except in November 1980 and between July and September 1982 when runoff was second to that from the bare plot probably as a result of the satured overland flow which normally occurred in the plot following persistently heavy and prolonged rainstorms.

Month	Rainfall (mm)	Runoff in mm			as % of rainfall		
		A	B	C	A	B	C
April	48.8	5.0	3.0	1.4	10.2	6.1	2.9
May	141.6	21.5	11.7	7.4	15.2	8.3	5.2
June	95.5	12.0	9.2	8.3	12.6	9.6	8.7
July	150.0	15.9	10.4	7.2	10.6	6.9	4.8
August	280.3	32.9	25.1	17.8	11.7	8.9	6.4
September	383.0	41.8	31.4	23.8	10.9	8.2	6.2
October	267.0	29.1	25.2	18.0	10.8	9.4	6.7
November	50.7	4.7	2.8	3.6	9.2	5.4	7.1

Tab. II : Rainfall and runoff : April to November 1980.

Most of the rainfall erosivity indices correlate significantly with each other except mean intensity and antecedent precipitation index which show no clear trend with the other parameters (Tab. III).

Runoff correlated with	Plot A	Plot B	Plot C
1. Rainfall amount	0.83*	0.72*	0.87*
2. Mean intensity	0.17	- 0.08	0.01
3. Peak intensity	0.83*	0.73*	0.87*
4. AI_{15}	0.77*	0.68*	0.80*
5. EI_{30}	0.86*	0.56*	0.78*
6. EI_{15}	0.83*	0.56*	0.78*
7. KE>25	0.72*	0.56*	0.62*
8. A.P.I.	0.38	0.14	0.24

Tab. III : Correlation between runoff from the plots and some erosivity parameters (1980-1982). * Significant at 0.01 level.

As it is obvious from the above table, runoff correlates more significantly with both rainfall amount and peak intensity, both of which also correlate very significantly (r-value = 0.99, table VII). The degree of correlation between runoff and the rainfall parameters varies from plot to plot, being highest in the forest plot with r-value of 0.87 for each of rainfall amount and peak intensity. The r-value in the bare plot is 0.83 for each of these parameters while it is 0.72 and 0.73 respectively in the maize plot. AI_{15} has r-values of 0.80, 0.77 and 0.68 respectivly in plots C, A, and B; while the r-values of the EI_{30}, EI_{15} and KE>25 are 0.56 in plot B (maize plot). In plot C, the r-value is 0.78 for the EI_{30}, and the EI_{15} and 0.63 for KE>25.

Soil loss

The annual values of soil loss declined steadily from the inception of the study in 1980 (Tab. IV).

Year	Plot A	Plot B	Plot C
1980	232.61	157.35	124.23
1981	172.72	107.49	87.54
1982	68.00	16.60	25.00
Mean	157.80	93.80	78.90

Tab. IV : Soil loss from 1980-1982 (kg/ha).

The monthly pattern of soil loss varies a great deal. For instance in 1980, the lowest value was obtained in plot A in April while the highest occurred in August, but in 1982, soil loss from all the plots was very low in April rising to a maximum in June declining in July to August to reach the peak in September or October - the wettest months (Tab. V).

Month	Plot A TS*	Plot A SS	Plot A DS	Plot B TS	Plot B SS	Plot B DS	Plot C TS	Plot C SS	Plot C DS	Rainfall in mm
June	15.34	7.45	7.89	6.56	3.38	3.18	2.82	0.64	2.12	77.50
July	2.32	1.47	0.86	1.03	0.70	0.35	1.89	0.83	1.05	78.60
Aug.	0.04	0.02	0.02	0.03	0.01	0.02	0.17	0.12	0.04	29.90
Sept.	5.78	4.46	1.31	1.60	0.84	0.76	6.62	2.18	4.44	133.80
Oct.	22.33	18.25	4.08	2.21	1.01	1.20	5.24	1.50	3.74	152.20
Nov.	0.30	0.16	0.14	0.03	0.01	0.02	0.42	0.08	0.34	14.60

Tab. V : Pattern of sediment production in the plots June - November 1982 in kg/ha. TS : total sediment load; SS : suspended sediment; DS : dissolved sediment load.

The relationship between suspended and dissolved load varied from plot to plot; the ratio ranged between 1:1 to 1:4 (Tab. V). While suspended load was higher than dissolved in plots A and B, the latter was consistently higher than the former in the forested plot (C).

Of the total soil loss, suspended sediment constitutes 67.6 % in plot A, 51.9 % in plot B, and 31.6 % in plot C. As shown in table VI, the greater proportion of these sediments were produced during a few rainstorms over relatively short periods.

Plot	Month with highest soil loss	% of the total	Day with highest soil loss	% of the total
A	October	24.4	03/10/82	21.2
B	June	57.3	22/06/82	28.0
C	September	38.6	24/09/82	18.2

Tab. VI : Highest soil loss per month and per day in 1982.

The high percentage loss from plot A can probably be attributed to the heavy high intensity rainfalls in October which generated a large volume of runoff from the plot. The loss in plot B in June was probably due to the harvesting of the early maize and the preparation of the plot for the late maize, while for plot C, this was due to the cumulative effects of rainfall up till September when large volumes of satured overland flow were generated in the plot.

The mean annual soil loss of 157.8 kg/ha/yr from the bare plot (A) compares favourably with the 180 kg/ha (0.18 mm) obtained bey LEOW & OLOGE (1981) in the savanna (Zaria) area of northern Nigeria, but it is lower than the 2.3 tonne/ha obtained for a similar surface in Rhodesia (Zimbabwe) by HUDSON & JACKSON (1959). The mean annual soil loss of 93.8 kg/ha/yr obtained from the maize plot is about the same as 101.6 kg/ha obtained by LAL (1976) from a similar plot on a 15 % slope in Ibadan. The mean annual soil loss of 78.9 kg/ha/yr from the forest plot is higher than what CHARREAU (1972) obtained from a ferralitic soil in Abidjan in an area with a total rainfall of 2100 mm. It is also higher than the 40 kg/ha/yr obtained in the headwater of the Gombak river in Malaysia by DOUGLAS (1972).

The average soil loss per rainfall event was 1.52 kg/ha, 0.37 kg/ha, and 0.55 kg/ha from plots A, B and C respectively. These compare favourably with those obtained by KELLMAN (1969) from 8 m^2 plots in upland Mindanao region, Phillipines. From a new rice swidden during the cropping period, KELLMAN (1969) obtained 0.81 kg/ha/day, and 0.43 kg/ha/day during the harvesting period.

Interrelationships between soil loss and rainfall parameters

Soil loss from all the plots correlates most significantly with runoff, and this accords with the findings by JEJE (1977) in the same general area, and by EMMETT (1970), and HADLEY & McQUEEN (1961) in the United States. Correlation is highest in the bare plot (A) with 0.91, and lowest with 0.73 on the forested plot (C). The EI_{30} and the EI_{15} indices also correlate significantly with soil loss from the bare plot (Tab. VII), while they are of less significance on the other plots (HUDSON, 1971). However, contrary to the findings of ELWELL & STOCKING (1975), the EI_{15} index is not highly correlated with soil loss from the maize plot. In fact with r-value of 0.58, this index appears to correlate more with soil loss from the forest.

With r-value of 0.71, KE>25 correlates highly with soil loss from the bare surface, and this accords with HUDSON's (1971) findings in Rhodesia (Zimbabwe). As expected, peak rainfall intensity correlates highly with soil loss in all the plots, being the second most significant after rainfall amount on plots B and C. The AI_{15} index also correlates significantly with soil loss on all the plots (AINA *et al.*, 1977). The lowest r-values are recorded between soil loss and mean rainfall intensity, the value is even negative in plot B. Although antecedent precipitation index correlates very highly with runoff, it however, correlates very poorly with soil loss especially in the vegetated plots.

Mutivariate relationship

Equations (v) - (vii) show the relationship between soil loss and the erosivity parameters (key of the symbols is the same as table VII).

$$\text{Log } Z_1 = -1.667 + \log 1.002\, S_1 - \log 2.926\, S_4 + \log 0.086\, S_5 + \log 3.231\, S_6 - \log 0.085\, S_8 - \log 0.174\, S_9 + \log 0.096\, S_{10} - \log 0.062\, S_{11}$$

$$R^2 = 0.86 \qquad \text{(v)}$$

$$\text{Log } Z_2 = 1.715 + \log 0.957\, S_2 + \log 2.966\, S_4 - \log 0.216\, S_5 - \log 2.967\, S_6 + \log 0.093\, S_7 - \log 0.167\, S_8 - \log 0.018\, S_9 + \log 0.014\, S_{10} + \log 0.259\, S_{11}$$

$$R^2 = 0.81 \qquad \text{(vi)}$$

	Z_1	Z_2	Z_3	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	S_{11}
Z_1	1.00	0.64	0.58	0.91	0.70	0.74	0.76	0.08*	0.77	0.70	0.75	0.75	0.71	0.37*
Z_2		1.00	0.57	0.58	0.87	0.56	0.64	0.19*	0.60	0.58	0.41	0.39*	0.49	0.18*
Z_3			1.00	0.57	0.60	0.73	0.72	0.18*	0.70	0.64	0.55	0.58	0.48	- 0.01*
S_1				1.00	0.69	0.81	0.83	0.17*	0.83	0.77	0.86	0.83	0.72	0.38*
S_2					1.00	0.66	0.72	0.08*	0.73	0.68	0.56	0.56	0.56	0.14*
S_3						1.00	0.87	0.01*	0.87	0.80	0.78	0.78	0.62	0.24*
S_4							1.00	0.02*	0.99	0.93	0.85	0.85	0.68	0.36*
S_5								1.00	0.01*	0.02*	0.03*	0.18*	- 0.05*	- 0.21*
S_6									1.00	0.93	0.85	0.87	0.67	0.39*
S_7										1.00	0.85	0.80	0.64	0.45
S_8											1.00	0.88	0.67	0.48
S_9												1.00	0.73	0.33*
S_{10}													1.00	0.46
S_{11}														1.00

Tab. VII : Correlation matrix showing the relationship between soil loss and the rainfall erosivity parameters. Z_1 : soil loss from plot A; Z_2 : soil loss from plot B; Z_3 : soil loss from plot C; S_1 : runoff from plot A; S_2 : runoff from plot B; S_3 : runoff from plot C; S_4 : rainfall amount; S_5 : mean rainfall intensity; S_6 : peak intensity; S_7 : AI_{15}; S_8 : EI_{30}; S_9 : EI_{15}; S_{10} : KE>25; S_{11} : A.P.I. * relationship not significant at 0.1 all others significant at 0.1.

$$\text{Log } Z_3 = 1.279 + \log 0.475\, S_3 + \log 2.045\, S_4 + \log 0.354\, S_5$$
$$- \log 1.225\, S_6 + \log 0.079\, S_7 - \log 0.208\, S_8$$
$$- \log 0.065\, S_9 + \log 0.536\, S_{10} - \log 0.545\, S_{11}$$
$$R^2 = 0.70 \qquad \text{(vii)}$$

Table VIII shows the R^2 (coefficient of determination) values which measure the magnitude of the influence of each erosivity parameter on soil loss from each of the erosion plots A, B, C.

Soil loss from	Runoff	Rainfall amount	Peak intensity	Mean intensity	AI_{15}	EI_{30}	EI_{15}	KE>25	A.P.I.	Total
Plot A	0.827	0.013	0.003	0.000	0.000	0.005	0.006	0.007	0.000	0.861
Plot B	0.756	0.001	0.018	0.015	0.007	0.002	0.007	0.006	0.002	0.814
Plot C	0.532	0.065	0.029	0.021	0.002	0.006	0.002	0.006	0.037	0.700

Tab. VIII : R^2 values due to each rainfall parameter in the regression equations.

Both the equations and table VIII show that runoff is the most important predictor of soil loss from each plot accounting for 83 %, 76 % and 53 % of the variation in soil loss from plots A, B, oand C respectively. On plot A, runoff is followed in order of importance by KE>25 and EI_{30} while A.P.I., and mean intensity appear unimportant. On plot B, following runoff in order of importance are peak and mean intensity, AI_{15}, EI_{15} and KE>25. On plot C, following runoff in order of importance are rainfall amount, A.P.I., peak intensity, KE>25 and EI_{30}. All the erosivity parameters examined explain a total 86 %, 81 % and 70 % of the soil loss variances from plots A, B and C respectively.

DISCUSSIONS

The three main findings in this study are as follows :

- For the duration of the study, the bare plot produced the highest values of both runoff and soil loss followed distantly by the maize and the forest covered plot. Values of soil loss from all the plots declined steadily from 1980 to 1982, and the forest plot suffered more soil loss than the maize plot in 1982.

- As sediments are normally transported in suspension, as is to be expected, runoff appears to be the best predictor of soil loss from all the plots accounting for 83 %, 76 % and 53 % of the soil loss variance in plots A, B and C respectively.
- Both the EI_{30} and the EI_{15} indices believed by STOCKING & ELWELL (1973) to be the best predictor of soil loss from bare and vegetated surfaces respectively in Rhodesia (Zimbabwe), also appear strongly related to soil loss in the study area. However, the KE>25 index appear to be more significantly related to soil loss on the vegetated plots than the EI_{15} index.

That both soil loss and runoff were highest in the bare plot was not unexpected as this merely confirms the findings by other workers such as WISCHMEIER & SMITH (1962), HUDSON (1971), STOCKING & ELWELL (1973, 1976), and LAL (1976) among others. However, high values of runoff and soil loss were unexpectedly recorded in the forest plot, and this contrasts with the findings of HEWLETT & HIBBERT (1967), KIRKBY (1969), REINHART *et al.* (1963), ROTHACHER (1965), WHIPKEY (1969) among others who worked in the forested areas in humid temperature regions. However, PIERCE (1967), RUXTON (1967) and KESSEL (1977) observed overland flow and slope wash in the forested temperature region of the United States, tropical New Guinea and Guyana respectively.

With regard to the forest plot (C) in the study area, the high volume runoff and soil loss observed especially in November 1980 and between July and September 1982 may not be unconnected with the exposure of a significant part of the mineral soil surface especially as litter cover and ground layer were rather sparse in the disturbed forest. As observed by TACKETT & PEARSON (1965), following initial wetting during a high intensity rain storm, the clay in such soils can expand and seal the surface layer to make the condition favourable for the generation of overland flow. This is especially the case as rain can directly fall on the soil through canopy gaps or through stem-flow. The latter has been estimated at between 5 % (ZINKE, 1967) and 29 % (FRIESE, 1936) of the total precipitation in the rain forest. With direct rain drop impact with the ground surface, this can seal the surface layers and generate overland flow especially when there is a high intensity rain. Thus it is not surprising that both runoff and rainfall amount are the best predictors of soil loss from the forest erosion plot. Also as most of the area upslope of the forest plot is cultivated to cocoa, with its characteristic thick surface litter, drainage in such areas is mainly subsurface.

Following persistent rainfall, locations downslope as in the case of the forest plot can experience saturated overland flow which can persist long after the rains have ceased as occurred in the plot.

Sediment yield declined steadily in all the plots from 1980 to 1982 possibly because as the fine soil aggregates were being removed, this led to the concentration of the more coarse fractions which became more and more difficult to entrain except during exceptionally high intensity storms. Thus by the end of the exercise in November 1982, gravel concentration could be observed on the bare plot.

Generally, runoff was persistently low in the maize plot (B) due to mulching by maize stover and the cleared refuse, the high maize density and foliage cover. The mulch substantially reduced runoff and soil loss because of increased surface detention and the decreased rate of runoff (BORST & WOODBURN, 1942). Also the mulch absorbed rain water transmitting it into the soil at a slow rate. Also the maize canopy intercepts rain-drops so that their energy was considerably reduced. However, during the periods when the maize crops were immature and the maize stover of the previous season decayed, rain drops were highly erosive, and this possibly account for the relative importance of the KE>25 and AI_{15} indices as predictors of soil loss from this plot.

The r-values in table VII show that runoff correlates most significantly with soil loss from all the plots than all the other erosivity parameters considered. This shows that while rain drop impact may be very important in soil detachment on many surfaces - woodland, savanna, cropped land etc ... (e.g. SOYER *et al.*, 1982), it would appear that rain drop impact without a transporting agent may be incapable of causing significant downslope sediment movement.

LAL (1976) and AINA *et al.* (1977) found that AI_m correlated more significantly with soil loss on bare surfaces than the EI_{30} index. This is not confirmed by the present study, rather, it appears that the EI_{30} and the EI_{15} indices are more significantly related to soil loss on bare plot while in the maize and forest plots, the AI_m index is more significantly related to soil loss than either the EI_{30} or EI_{15}. In fact the EI_{15} appears relatively unimportant as a soil loss predictor from the maize plot in this study.

The KE>25 index is however, positively and significantly related to soil loss in all the plots, but it is more important on the bare plot (A) where it has r-value of 0.71 than in plots B and C where the r-values are 0.49 and 0.48 respectively. The kinetic energy of rainfall with intensity greater than 25 mm/hr would appear to be more important in rainsplash erosion especially on bare soils as in plot A, the effect, however, appears muted by vegetal cover in plots B and C. This confirms HUDSON's (1965) results that the KE>25 index may be better indicator of soil loss from bare soils.

Rainfall amount which has been recognised as an important parameter in the soil loss equation (ELWELL & STOCKING, 1973 b) also proves to be significantly correlated with soil loss in this study. It is third in importance in plot A, and second in plots B and C. It, however, shows no significant contribution in the multiple regression equations.

Although the antecedent precipitation index (A.P.I.) correlates poorly with soil loss in all the plots with r-values of 0.36, 0.17 and 0.01 in plots A, B and C respectively, it however, makes a contribution of 0.012 %, 0.2 % and 3.7 % to the total variation in soil loss in plots A, B and C respectively. Where its contribution is positive, this is rather marginal as in plots A and B. Thus the A.P.I. which is not significant in plot A appears to be significant in plots B and C where soil loss depends mainly on the amount of precipitation that enters the plot to recharge the soil to field capacity after which runoff can be initiated.

CONCLUSION

An attempt was made in this study to examine the effects of different land use/vegetal cover on soil loss and to determine the most important erosivity parameters relative to soil loss from these various surfaces.

As already indicated the amount of runoff and soil loss was consistently greatest from the bare surface (plot A), followed distantly by the maize plot (B), while both runoff and soil loss were lowest in the forest plot (C) in 1980 and 1981. In 1982, runoff and soil loss were lower from the maize plot than from the forest plot.

While temporal variations occurred in the production of runoff and sediment from the plots, it is quite evident that the same volume of runoff and rainfall may not necessarily yield the same amount of sediment from the same plot. It also appears that only very few storms were actually responsible for generating most of the soil loss during the study period.

As expected soil loss correlates most significantly with runoff in each plot. It is followed in the bare plot (A) by peak intensity, rainfall amount, EI_{30}, EI_{15}, KE>25 and AI_{15} indices in that order. In the maize plot (B), runoff is followed in order of importance by rainfall amount, peak intensity, AI_{15}, KE>25 and EI_{30}. In the forest plot (C), runoff, rainfall amount, peak intensity and the AI_{15} index correlate significantly with soil loss, while the EI_{30}, EI_{15} and KE>25 indices correlate indices correlate least with soil loss from this plot.

The result obtained from the stepwise multiple regression analysis shows that runoff is the most significant predictor of soil loss in all the plots accounting for about 83 %, 76 % and 53 % of soil loss variances from plots A, B and C respectively. On the whole, the erosivity parameters examined explained a total of 86 %, 81 % and 70 % variation in soil loss from plots A, B, and C respectively.

As runoff correlates so significantly with soil loss from these plots, perhaps one way of minimising sediment loss and thus reducing soil erosion is to reduce surface runoff by enhancing rain water infiltration into the soil through ensuring adequate vegetal, litter and mulch cover on soil surfaces.

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