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RATES OF SOIL WASH UNDER SAVANNA CLIMATE
(Zaria, Northern Nigeria)

Vitesse d'érosion des sols sous un climat de Savane
(Zaria, Northern Nigeria)

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RESUME

Vingt-sept collecteurs d'eau de ruissellement ont été installés sur des pentes couvertes d'un recru de broussailles basses sous un climat de savane (Campus principal de l'Ahmadu Bello University, à Zaria). Les sédiments recueillis pendant les trois derniers mois de la saison des pluies témoignent d'une pellicule érodée de 0,18 mm. La vitesse d'érosion des sols montre une forte corrélation négative avec la pente et aussi avec l'indice de couverture foliaire. Cette vitesse est aussi plus faible sur les versants couverts de dépôts de colluvions que sur ceux qui en sont dépourvus. A l'exception du plus faible pourcentage de gravier, la composition granulométrique du sédiment piégé est peu différent de celui de l'horizon superficiel du sol. L'utilisation des coefficients de corrélation partielle montre que le facteur le plus important de la vitesse d'érosion est le couvert végétal, puis la pente des versants et enfin la teneur en gravier de l'horizon superficiel.

ABSTRACT

Twenty seven wash traps were established on slopes with low scrub regrowth vegetation under Savana climate on the Ahmadu Bello University Main Campus, Samaru, Zaria. The sediments collected during the last three months of the rainy period show the loss of an average of 0.18 mm of ground thickness. The rate of soil wash shows strong negative correlations with slope gradient and also with leaf cover index. The rate of soil wash is also lower on debris-covered-slopes than on non-debris-covered-slopes. Apart from the lower gravel content, the mechanical composition of the sediment caught is very similar to that of the top soil. By using the partial correlation coefficient, it is observed that vegetation cover is the most important factor, followed by slope

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gradient, and finally, the gravel content of the top soils, in determining the rate of soil wash.

INTRODUCTION

Much has been written about the problem of soil erosion in Nigeria, and especially in the Savanna areas. But most of what has been written is based on deductive reasoning from first principles (see for example, OLOGE, 1973). However logical such reasoning may seem, they need to be validated with empirical data. Experimental studies of soil erosion under different types of land management have been carried out at Samaru (KOWAL, 1970). These are welcome and should be continued. There is also a need to extend such studies to seminatural and natural ecosystems. Data arising from such studies should provide the much needed empirical base for scientific discussion fo the soil erosion problem.

This study, which is essentially exploratory, is concerned with the measurement of soil wash under low scrub regrowth vegetation on the Ahmadu Bello University Main Campus at Samaru, Zaria.

Environment

Soil wash measurement was carried out in an area within the Ahmadu Bello University Campus, Zaria, which is located on the undulating High Plains of Hausaland. The area has tropical savanna climate with distinct wet and dry seasons (HORE, 1970) and a mean annual rainfall of approximately 1100 mm. Rainfall, which is concentrated in the wet season between May and October, is mostly in the form of storms, with an average intensity of 80 mm/hr.

The solid geology is biotite gneiss. But this has been deeply weathered and lateritized. The lateritized landscape was then dissected and eroded, the laterite being extensively redistributed as secondary laterite, locally described as the Younger Laterite (McCURRY, 1970). This is exposed in some places but is usually covered by drift which is particularly aeolian in origin.

The slopes where the wash traps were located are valley side slope of first and second order valleys and all less than 20 m long. The area supports two distinct types of soil, namely gravelly lithosol on debris-covered slopes and ferruginous tropical soils with sandy loam texture on non-debris-covered slopes.

The vegetation cover in this area is semi-natural, with high variation in density. The vegetation is mainly a low regrowth of tree and shrubs, such as *Isoberlinia doka*, *Isoberlinia tomentosa*, *Uapaca togensis* together with a tall tufted grass layer of *Andropogon* sp.

METHODOLOGY

Wash traps were established on slopes of three adjacent small catchments inside the main campus of A.B.U. These wash traps were the conventional type (YOUNG, 1960), with a 25 cm lip. They were placed on different slope gradients, slope positions and densities of vegetational cover. The traps were installed around the third week of July, and remained in the field until the end of November, when collections were made. Although 35 wash traps were initially installed, only 27 were used for analysis; the others were either missing or had been disturbed.

The sediments collected were first removed from the wash traps, dried and weighed. The raw organic matter was then separated from the mineral fraction. The latter was divided into the gravel fraction (> 2 mm) and the fine earth fraction (< 2 mm). About 100 g of the fine earth fraction were separated out with the help of a sample seperator. The proportion of the sand (50 - 2000 μ) and silt/clay (< 50 μ) fractions were obtained by the wet sieve method.

Leaf cover index was measured by the quadrat method. Slope angles were measured with an Abney level. Distances away from crest and the total slope ranges were measured by tape.

RESULTS

Amounts of material collected from wash traps

The amounts of sediment collected from the traps varied considerably, ranging between 4916 g and 21 g, with an average of 1280 g. Most of the sediments (over 85 %) collected were between 200 and 2500 g. Expressed in volumetric terms, the amounts of sediment crossing the lips of the traps range from 0.32 cm^3/cm to 74.70 cm^3/cm with an average of 19.31 cm^3/cm, mostly (over 80 %) between 3.5 cm^3/cm and 40 cm^3/cm.

An attempt was made to convert the amount of sediment caught in the traps into the thickness of soil removed from upslope. The results show that at the place of maximum rate of erosion, a thickness of 0.57 mm of soil has been removed from upslope. However, most of the slopes (over 80 %) lost between 0.1 mm and 0.4 mm thickness of soil. The average thickness removed from this area is 0.18 mm during the 3 months (roughly half of the rainy season). This roughly amounts to removing 1 cm of soil every 28 years or 1 m soil in 2800 years.

Soil wash related to slope properties, density of vegetation cover and surface materials

An attempt was made to relate the amounts of sediment caught in the wash traps (i.e. rates of transport by soil wash) to three slope elements : slope gradient, slope position and slope curvature. No significant relationship exists between the rate of soil wash and either slope position or curvature (coefficients of correlation are + 0.07 and - 0.17 respectively). However, the rate of soil wash shows a strong negative correlation with slope gradient (coefficient of correlation is - 0.63, significant at 0.001 level), i.e. the greater the slope gradient, the less the amount of sediment caught in the wash traps (Fig. 1).

The other factor that may control the rate of soil wash is the density of vegetation cover. Leaf cover index (LCI) was used as an index for vegetation density. The LCI varies a lot in this area, ranging from 68 % to 11 % with an average of 38 %. The LCI shows no significant relationship with the three slope properties (the correlation coefficients are all less than 0.10).

There is a strong negative correlation between the rate of soil wash and LCI (coefficient of correlation is - 0.60, significant at 0.001 level). This means that the higher the vegetation density, the lower is the rate of soil wash.

The other factor considered here that may affect the rate of soil wash is the surface materials. On the basis of the surface materials, slopes in the study area can be divided into two types, the debris covered slopes and the non-debris-covered slopes. The mechanical composition of the surface materials in these two types of slope is different; debris-covered slopes contain much higher amounts of gravel and sand, but less silt/clay than non-debris-covered slopes (Tab. I)

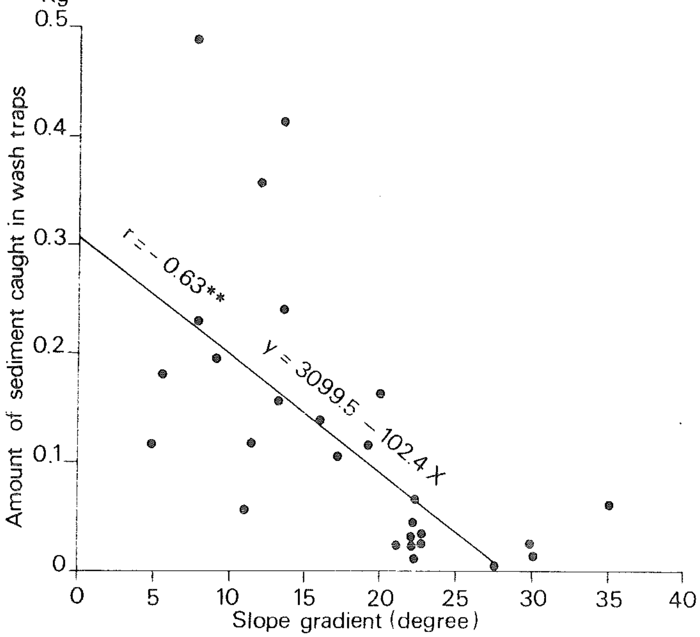

Fig. 1 : Relationship between the amount of sediment caught in wash traps and slope gradient. (** significant at 0.01 level).

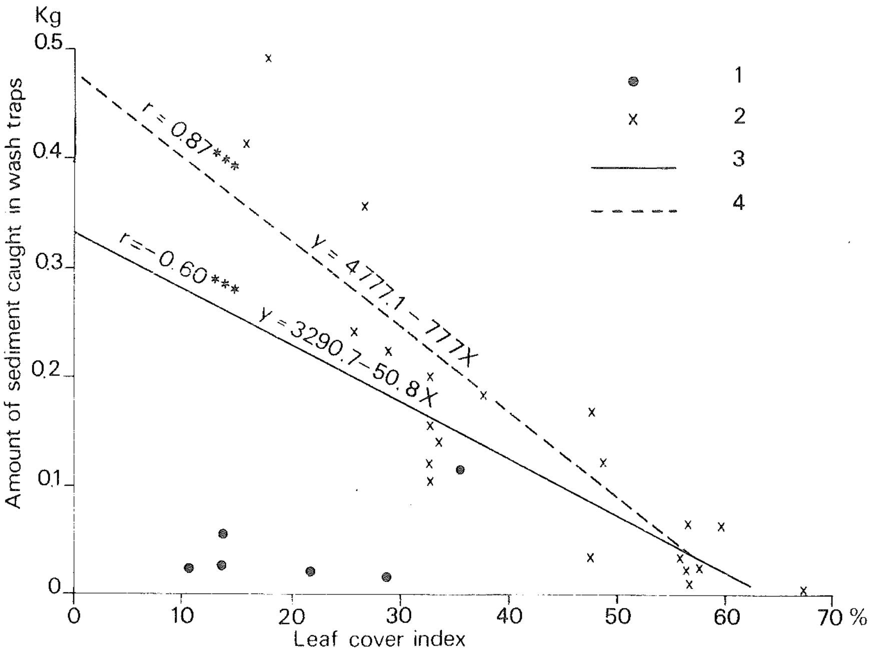

Fig. 2 : Relationship between the amount of sediment caught in wash traps and leaf cover index (LCI). (*** significant at 0.001 level), 1 : Wash traps on debris-covered slopes; 2 : Wash traps on non-debris-covered slopes; 3 : Regression line between the amount of sediment caught in wash traps and LCI; 4 : Regression line between the amount of sediment caught in wash traps on non debris-covered slopes and LCI.

	No of samples	Mean gravel (as % of fine earth)	Mean sand (%)	Mean silt/clay (%)
Debris-covered slopes	7	186	60	40
Non-debris-covered slopes	20	23	43	57

Tab. I : Mechanical composition of the surface materials on the two types of slope in the study area.

The sediments caught in the wash traps show significant differences between these two types of slope. The amount of sediment caught on debris-covered slopes is nearly 2.5 times less than the average amount of sediments caught in non-debris-covered slopes (Tab. II). The difference between these two sets of measurements was tested by student "t" test and was found to be statistically significant at the 0.025 level.

	Debris-covered slopes		Non-debris-covered slopes	
	Amount of sediment	Rate of transport	Amount of sediment	Rate of transport
Average	663.14 g	10.08 cm^3/cm	1,496.35 g	22.75 cm^3/cm
Number of sample	7	7	20	20
Standard deviation	680.53 g	10.34 cm^3/cm	1,369.19 g	20.81 cm^3/cm
t value 2.08* (sig. different at 0.025 level)				

Tab. II : Amounts of sediment and corresponding rates of transport by soil wash on the two types of slope in the study area.

The relationship between the rate of soil wash and the three independent variables, i.e., slope gradient, leaf cover index, gravel content (as an index for properties of surface material), is further analysed by using coefficient of partial correlation. This involves measurement of the correlations between a dependent variable and one particular independent variable when all other variables included are kept constant, i.e. when their effects are removed. The result of these analyses are as follows : the partial correlation coefficient between the rate of soil wash and leaf cover index is equal to - 0.58, and with the slope gradient is equal to - 0.45 and with the gravel content is - 0.21.

For these results, it is possible to say that leaf cover index (i.e. density of vegetation cover) is the most important in determining the rate of soil wash, followed by slope gradient and then the gravel content in the top soils.

Composition of sediments caught in wash traps

The sediments caught in wash traps were separated into raw organic matter (litter), gravel (> 2 mm), sand (50 μ - 2000 μ) and silt/clay (< 50 μ).

All but three of the sediments trapped contained very low amounts of raw organic matter (less than 7 %) and the amounts of raw organic matter show no significant relationship with slope properties, densities of vegetation cover, or surface material. This may indicate that the variation of raw organic matter is either independent or is random.

The gravel content, expressed as percent of the fine earth fraction (< 2 mm) is fairly low in wash traps located on non-debris-covered slopes (all but two are less than 10 % gravel; these other two are less than 20 %), and fairly high in debris-covered slopes (all but two cases are over 67 %; and even the others are higher than 20 %) (Tab. III). However, no significant relationship was found between gravel content on the one hand and slope properties and vegetation density on the other.

	Debris-covered slopes	Non-debris-covered slopes
Average	100.42	5.00
Number of sample	7	20
Standard deviation	66.04	5.33
t value 3.81 (sig. different at 0.0005 level).		

Tab. III : Gravel contents in sediments caught on two types of slope.

The mechanical composition of the fine earth sediment ranges from 30 % sand, 70 % silt/clay to 73 % sand, 27 % silt/clay. Sediments collected on debris-covered slopes tend to have higher sand and lower silt/clay content than sediments collected on non-debris-covered slopes (Tab. IV).

	Debris-covered slopes	Non-debris-covered slopes
Average	58.7	44.9
Number of sample	7	20
Standard deviation	8.45	9.38
t value 3.41 (sig. different at 0.001 level).		

Tab. IV : Sand content (percent) in sediments collected on two types of slope.

The percentage of sand fraction also correlated with the relative slope position (i.e. distance away from crest/total length of slope x 100 %). High sand fraction occurs near the basal area; low sand fraction toward the crest (Fig. 3). The proportion of sand also increases with distance away from the crest. However, this trend is not statistically significant and no relation exists between sand content on the one hand and slope gradient, and density of vegetation cover on the other.

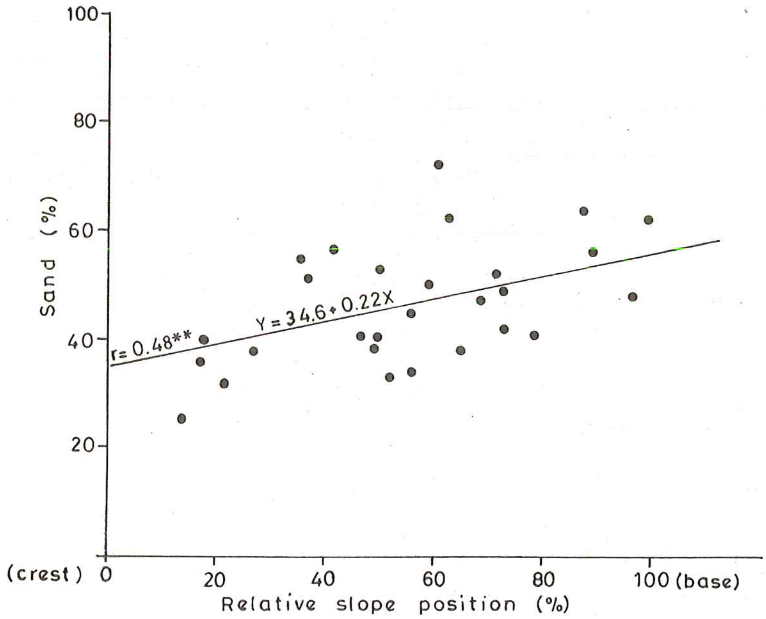

Fig. 3 : Relationship between the proportion of sand in sediment caught in wash traps and relative slope position. (** significant at 0.01 level).

Comparison between sediments caught and nature of top soils

Comparison of the sediments caught in wash traps and the top soils shows that the mechanical composition in the fine earth fraction is very similar (Tab. V). However in the gravel fraction, all the sediments caught in the wash traps show much less amount of gravel compared with the top soils. The top soils had an average of 23 % gravel (expressed as percentage of fine earth) on non-debris-covered slopes and 186 % on debris-covered slopes. However, in the sediments caught, the average gravel content is 5 % on non-debris-covered slopes and 100 % on debris-covered slopes.

	Sediments	Top soils
Average	52.5	55.3
Number of sample	30	30
Standard deviation	12.75	9.88
t value 1.21 (no significant difference)		

Tab. V : Sand content (percent) in sediments collected on wash traps and in the top soils.

DISCUSSION

The present study has recorded the loss of an average of 0.18 mm of ground thickness in about three months period during the rainy season. This figure is much higher than the results obtained by WILLIAM (1968) in northern Australia. The rate of soil wash in that area represents a lowering of only 0.039 mm/yr which is about 8 times smaller than in this study (assuming that the three months is half of the rainy season).

The higher results of this study may be due to high intensity of grazing in the study area. SCHUMM (1964) describes how the disturbance of the surface by animals can move material downhill. The high rate of erosion also confirms that soil wash is a most important process of denudation under a savanna climate.

The negative relationship between the rate of soil wash and slope gradient presents some interesting problems. In all earlier studies, the rate of soil wash either increased with increasing slope gradient (YOUNG, 1973; SCHUMM, 1956, 1962) or had no significant variation with slope gradient (YOUNG, 1958; KIRKBY, 1963; LEOPOLD *et al.*, 1966). In theory, the greater the slope gradient, the higher the velocity of the moving water; therefore, the higher the soil wash. However, soil wash can be divided into two distinct processes : soil detachment and wash transport. Only the latter varies significantly with slope gradient. YOUNG (1972) has pointed out that if soil wash is controlled by rate of soil detachment, the rate of ground loss will be little affected by slope angle, since the main agent of detachment in most area is raindrop which does not vary with slope angle. In the study area, the activities of grazing animals may be the important agent in detaching the soil. Cattle tend to stay more on level ground than on steep slopes, and may therefore cause more soil detachment in areas of low gradient.

The significant relationship found between the rate of soil wash and the density of vegetation cover in this study agrees with previous studies (GABERT, 1964; RENNER, 1936; MEGINNIS, 1935). HUDSON & JACKSON (1959) found that the rate of wash under a similar climate varied greatly with different degrees of vegetation cover in Rhodesia. Vegetation influences soil wash by reducing the quantity and velocity of overland flow, either by increasing the infiltration rate of the soil (CARSON & KIRKBY, 1972) or by intercepting the raindrops. The common trees in this area intercept up to 50 % of the rain at the intensity of 60 mm/day (unpublished data). The reduction of overland flow would reduce soil wash, since soil wash is closely related to the rate of runoff (CARSON & KIRKBY, 1972).

The lower rate of soil wash on debris-covered slopes may be due to, firstly, the top soils having high amount of gravels, which are difficult to detach and transport. Secondly, the coarse soil texture on these slopes increases the infiltration rate, therefore there is less surface runoff to cause surface wash. Finally, the lower amount of silt and clay means that there is less likelihood of the soil surface being sealed up through dispersion of fine particles and clogging of soil pores. This phenomenon of soil capping or sealing is very common in northern Nigeria (KOWAL, 1972).

Although surface runoff is capable of carrying up to 10 mm - gravel particles, the amounts of gravel in the sediments tend to be less than the gravel content in the top soils. This indicated that soil wash favours the removal of particles less than 2 mm. However, non significant difference exists between the texture of the fine earth fraction in the sediments trapped and in the top soils. This result agrees with the result obtained by YOUNG (1973) under a tropical rainforest climate in Malaya.

Although the rate of soil wash shows no significant relationship with slope position the mechanical composition do vary with relative slope position. However, this result does not necessarily contradict the above result of no selective removal in the fine earth fraction. High sand content near the crest, and low sand content toward the basal area in sediments trapped may be due to a similar pattern of textural variation of the top soils on these slopes as observed by LEOW & SMITH (in press).

Finally, by using partial correlation coefficient, it is observed that vegetation cover is the most important factor, followed by slope gradient and, finally properties of the top soils, in determining the rate of soil wash in the study area. Thus by increasing the vegetation cover, it may be possible to significantly reduce the magnitude of soil erosion by sheet wash in this area. The importance of this in soil conservation in savanna areas is clear.

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