Use of the universal soil loss equation to predict erosion in West Africa

E. J. Roose

Erosion has for centuries been an obstacle to development. Consequently, man has tried to remedy this in diverse ways (terraces, reservoirs, itinerant cultivation, etc.) that more or less take into account climatic, economic, and human circumstances. With the purpose of rationalizing the choice of erosion control methods, several authors have formulated equations linking solids transport of field scale to causal and conditional erosion factors.

Among these attempts, the universal soil loss equation is by far the best known and the most widely used on other continents as well as in the United States. This empirical equation is based on the statistical analysis of more than 10,000 plot-years of data of sheet and rill erosion on plots and small watersheds. The equation is

$$A = RKSLCP \quad [1]$$

in which erosion (A) is a multiplicative function of five determining factors: R, an index of rainfall erosiveness that is a product of maximum 30-minute intensity of the rain and its total kinetic energy; K, an index of the susceptibility of a continuously fallowed soil to sheet and rill erosion; SL, a topographic index including both the angle and length of the slope; C, a biological factor expressing the combined influence of vegetal cover and cultural practices; and P, an index showing the effectiveness of supporting erosion control practices, such as contouring.

Knowing the value of rainfall erosivity, soil erodibility, and slope, one can calculate the effectiveness of various erosion control techniques to use if one decides to introduce a cultivation system into an area without exceeding an acceptable erosion rate.

My purpose is to apply the equation to the experimental results obtained in West Africa by the French Office of Research Overseas (ORSTOM) and the French Institute of Applied Research (GERDAT) and define its limit of validity.

Procedure

The results came primarily from 13 stations measuring sheet and rill

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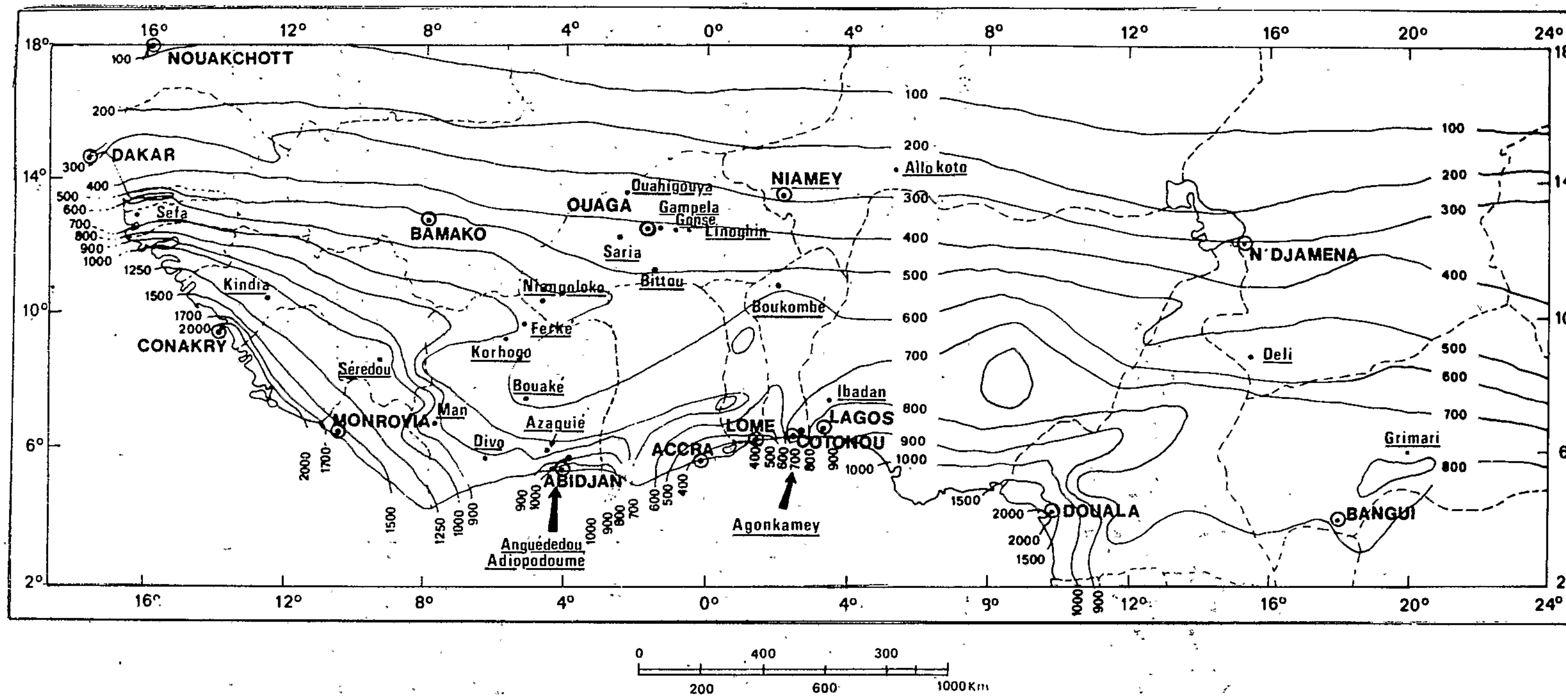

Figure 1. R index in West and Central Africa and location of runoff plots.

Table 1. Variability of index R as a function of the rainfall amount in West Africa.

Rainfall Amount (mm)	R Indexes at Different West African Locations											
	Abidjan		Divo		Bouake		Korhogo		Saria/Gonse		Allokoto	
	Extreme	Ave.	Extreme	Ave.	Extreme	Ave.	Extreme	Ave.	Extreme	Ave.	Extreme	Ave.
h = 15	0.5 to 8	5	1 to 7	4.5	0.5 to 7	3.7	1.5 to 7	5	2.3 to 6.5	4.7	1.5 to 8	5
h = 30	6 to 24	18	7 to 30	18	4 to 22	16	4 to 26	17	16 to 31	18	6 to 20	18
h = 50	12 to 66	44	20 to 90	48	15 to 80	40	19 to 80	50	30 to 65	48	30 to 65	50
h = 70	32 to 90	78	49 to 108	84	25 to 100	73	31 to 120	83	84 to 104	86	-	-

erosion on about 50 plots of 100 to 5,000 square meters located in five West African countries (Figure 1, Table 4). Climates vary from the dense subequatorial forest in the lower part of Ivory Coast (rain = 2,100 millimeters) to the steppe of the Sahelien plain of the Niger (rain = 500 mm). Aside from the Allokoto station located on a vertisol, all other stations are set up on ferrallitic and ferruginous tropical soils.

Results

The most significant results of experiments are shown here to demonstrate the advantages and the limitations of the universal soil loss equation in West Africa.

Rainfall Erosivity Index, R

On the old eroded surfaces of the African continent, as on the Great Plains and Corn Belt in America where the cultivated slopes are moderate to nearly level, it is the impact energy of raindrops that causes erosion. This impact energy sets into motion the destruction of aggregates while runoff water provides for the transport of detached particles.

On the bare plots of Adiopodoumé, it has been shown (*28*) that the amount of rainfall fails to explain the phenomenon of erosion if one does not simultaneously take into account soil water content before the rainfall and the maximal intensity of the rainfall during a sufficiently long period of time (20 minutes for solids transport and 10 minutes for runoff flow.)

In the Mediterranean and Sahelien zone, Heusch (*12*) and Roose (*24*, *34*) estimate that it is the exceptional 50- to 100-year-frequency rain that radically transforms the landscape. On the other hand, the results show that in dry or humid tropical environments the level of erosion depends on the sum of the 10 or 20 most severe rains in a year rather than the exceptional rainfall, taking into account existing well-developed vegetal cover. All this agrees with the principles contained in the climatic erosivity index of Wischmeier and Smith (*42*, *43*), which takes into account the combined effects of amount, maximal intensity, and duration of all significant rain.

Unfortunately, the analysis of rain gauge charts is extremely time-consuming. In an attempt to simplify the method, several authors (*4*, *6*, *11*) have noticed that excellent linear regressions exist between kinetic energy and the amount of rain; but that the regression between the maximal intensity (I_{30}) and the amount of rain is curvilinear; and the scatter of points is much greater (*4*, *26*). Several authors (*6*, *7*, *11*) have published an equation valid in Upper Volta and in Niger (and probably in all of West Africa) that permits the estimation of the R index as a function of the rainfall amount (H) and its maximum intensity in 30 minutes (I_{30}):

$$R = (0.0158\ H \times I_{30}) - 1.2 \qquad [2]$$

However, the study of the spatial distribution of this index of erosivity, R, poses a major difficulty in Africa due to the small number of stations equipped with a recording rain gauge and the short period during which they have been keeping records. On the other hand, these stations have had at their disposal for the last 20 to 50 years in West Africa a relatively dense network of measuring stations of the amount of daily rainfall, which allows the calculation of representative averages. We therefore have been led to study in detail the connection existing between the amount of daily rainfall and the index of rainfall erosivity, R. The results show that there exist strong variations of R for rainfall of the same amount and that this variation increases with the amount of rainfall (Table 1). On the other hand, the average amounts vary little from one station to another from the lower Ivory Coast as far as the Niger.

In the coastal zone of the lower Ivory Coast, a linear regression exists ($R = 0.577\ H - 5.766$) between this index (R) and the rainfall amount (H) for rainfall of the "June to September monsoon" type. A curvilinear regression exists for high intensity rainfall in the other months. This curvilinear regression is very similar for all the stations studied between Abidjan and Ouagadougou. Based on these regressions, one can transform long series of observations of daily rainfall in order to find satisfactory monthly and yearly averages (5% error) of the rainfall erosivity index and try to map their distribution (*28*). It has been stated, therefore, that a single empirical relationship exists between the yearly average erosivity index (Ram) over 5 to 10 years and the corresponding annual average of rainfall amount (Ham):

$$Ram/Ham = 0.50 \pm 0.05 \qquad [3]$$

This rate has been verified at about 20 rainfall recording stations in the Ivory Coast, Upper Volta, Senegal, Niger, and Tchad, with the exception of stations located around the mountains as well as in the area near the sea. This relationship [3] has permitted us to sketch the distribution of this index in Ivory Coast (*28*), in Upper Volta (*31*) and for the whole of West Africa (*32*, *33*). This sketch (Figure 1) is a guide the precision (5%) of which outside of mountainous and coastal zones is sufficient to permit the use of the universal soil loss equation.

Figure 1 shows that the rainfall erosivity is very high in the humid tropical regions and decreases almost parallel to the isorainfall lines between Abidjan (Ham = 2,100 mm; Ram = 1,200) and Ouagadougou (Ham = 830 mm; Ram = 430). This is explained by the correlation between the annual average precipitation in this region, the amount of the 10-year rainfall and the curves "intensity x duration" (*2*, *3*). Since rainfall is of the same type in all of this zone, it is no longer necessary to include the intensity of the rainfall in addition to its amount in order to evaluate the average rainfall erosivity, as several authors have proposed.

By way of comparison, let us point out that the index varies from 50 to 650 in the United States (*43*), 60 to 300 in Tunisia (*17*), 50 to 300 in Morocco (*14*), 60 to 340 in the South of France (*18*), 500 to 1400 in Ivory Coast (*28*), and 200 to 650 in Upper Volta (*31*).

Soil Erodibility, K

The laboratory tests being insufficient to class soils as a function of their susceptibility to sheet and rill erosion, Wischmeier suggested a study of this factor on reference plots of about 100 square meters, with a 9 percent slope and treated as bare-tilled fallow without the addition of any organic matter for three years. Many soils cultivated in Africa are not represented by slopes of 9 percent. We therefore have adapted this procedure by choosing slopes characteristic of the soils and the landscapes and by correcting the measurements with the aid of the topographic factor (SL). The soil erodibility index therefore is calculated with the following equation:

$$K = \frac{A}{R \times SL \times 2.24} \qquad [4]$$

where A is the erosion in tons per hectare, R is the rainfall erosivity index, SL is the topographic factor, and 2.24 the coefficient necessary to go from metric units (t/ha) to English units (t/acre). In the United States, the

Table 2. Measured index of erodibility (K) of various soil types used in this study.

Location	Soil Types	Measured K			No. of Measures	Source
		Max.	Min.	Value Used		
Adiopodoume	Low base-saturated ferralitic on argillic-sandy tertiary material	0.17	0.05	0.10	24	(*28*)
Agonkamey	Medium base-saturated ferrallitic on argillic-sandy tertiary material	0.11	0.03	0.10	4	(*38*, *28*)
Bouake	Eroded reworked ferralitic on granite	0.16	0.02	0.12	4	(*1*, *15*)
Korhogo	Impoverished, reworked ferrallitic on granite	0.02	0.01	0.02	6	(*32*)
Gampela	Tropical ferruginous on lateritic pan at 20 cm	0.32	0.05	0.25	5	(*6*)
Saria	Tropical ferruginous on lateritic pan at 50 cm	0.28	0.06	0.25	3	(*29*)
Sefa	Leached tropical ferruginous with stains and concretions	0.17[a]	0.05	0.25[a]	2	(*4*)

[a] The value used for K at Sefa is higher than the maximum value observed because organic matter was plowed into the soil the first year. The effects of this were not overcome in the short term of the experiment.

Table 3. Effect of slope on erosion and runoff as a function of vegetal cover and soil.

	Slope (%)	Erosion (mt/ha/year) Forest	Erosion Bare Soil	Erosion Cropped Soil	Runoff (%) Forest	Runoff Bare Soil	Runoff Cropped Soil
Adiopodoume 1965-1972	4.5	-	60	19	-	35	16
Ferrallitic soil on tertiary argillic-sandy materials	7	0.03	138	75	0.14	33	24
Average rainfall = 2100 mm	23	0.1	570	295	0.7	24	24
Séfa (Senegal). Clean cultivated crops from 1955 to 1962. Leached ferruginous tropical soil with stains and concretions				Slope			
			1.25%	1.50%	2.0%		
Average erosion (m t/ha/year)			5	8.6	12		
Annual average runoff (%)			16	22	30		

erodibility index, K, increases from 0.03 to 0.60 for progressively more erodible soils. Table 2 summarizes what few experimental results exist in West Africa.

Application of the soil erodibility nomograph (*45*) in evaluating the susceptibility of soils to erosion has given satisfactory results for the ferrallitic and ferruginous soils studied, with the exception of soils that were gravelly or covered with rocky debris that acts as a protective mulch. This is very important in tropical and mediterranean regions (*8*, *32*, *37*). At Korhogo, for example, not only is the factor K very low (0.02) but it diminishes proportionately as the gravel concentrates in the upper surface (Table 2).

		K Estimated by the Nomograph
Various ferrallitic soils	from tertiary sand	0.05 to 0.10
	from granite	0.10 to 0.15
	from schist	0.15 to 0.18
Ferruginous tropical soils from granite		0.20 to 0.30

Two conclusions can be derived from the overall results:

1. The variability of monthly and yearly measurements necessitates going ahead with replications in space and especially in time. The measurements should only be done on tilled fields for over three years without burial of organic matter. Working of the soil eliminates the surface seals formed by the beating action of rain. However, too much cultivation gives soil loss and runoff results lower than the corn or cotton plots. Therefore, one tillage in each rainy season and two or three cultivations and chemical weedings are enough to maintain the soil surface in the desired condition.

2. Ferrallitic soils are very resistant to erosion, and ferruginous tropical soils are clearly less resistant after two or three years of cultivation. This difference is explained by the low permeability of ferruginous

Table 4. Location, vegetal cover, soil, and rainfall at experimental sites.

Location	Years	Agency	Vegetation	Soil	Rainfall	Seasons
Adiopodoumé	1955-75	ORSTOM	Secondary evergreen forest	Impoverished ferrallitic	2100 mm	4
Anguédédou	1966-72	IRCA-ORSTOM	Rubber plantation (parallel to contours)	Impoverished ferrallitic on tertiary argillic-sandy material	2000 mm	4
Azaguié	1966-73	IFAC-ORSTOM	Secondary rain forest, irrigated banana plantation	Reworked ferrallitic on on schist	1800 mm	4
Divo	1967-74	IFCC-ORSTOM	Semi-deciduous dense forest	Reworked ferrallitic on granite	1750 mm	4
Bouaké	1960-75	IRAT-ORSTOM	Dense shrub savannah	Eroded ferrallitic on granite	1200 mm	4
Korhogo	1967-75	ORSTOM	Clear shrub savannah	Reworked ferrallitic on granite	1400 mm	2
Ouagadougou	1967-73	IRAT-ORSTOM-	Sparse tree savannah	Leached ferruginous on granite	850 mm	2
Sefa (Sénégal)	1954-68	ORSTOM-IRAT	Woodland	Leached ferruginous	1300 mm	2
Cotonou (Benin)	1964-68	ORSTOM	Dense thicket	Impoverished ferrallitic on tertiary argillic-sandy material	1300 mm	4
Boukombe (Benin)	1960-61	ORSTOM	Park savannah	Leached gravel-filled ferruginous on schist	1100 mm	2
Allokoto (Niger)	1966-71	CTFT	Shrub savannah	Vertisol/calcareous	500 mm	2

soils, their tendency to seal, their relatively high content of silt and fine sand, and their very low level of organic matter. It seems, therefore, that the spectacular erosion observed in Africa is due to the extraordinary rainfall erosivity rather than to a particular high erodibility of tropical soils. However, El Swaify (*9*) has shown that in Hawaii the range of erodibility of tropical soils is as great as in the temperate zone.

The Topographic Factor, SL

Most authors agree on the important role that slope (length, shape, and especially steepness) plays in the development of erosion, although erosion can sometimes start on slopes less than 2 percent (*10*). Zingg (*46*), summarizing experimentation carried out on the soils of the temperate American regions, showed that soil losses increase exponentially with slope steepness, the average exponent being close to 1.4.

On a ferrallitic soil rich in gravel (alfisol) in Nigeria, Lal (*16*) found that erosion increases with slope according to an exponential curve exponent 1.2 when the soil is bare, but that it is independent of the slope (1 to 15%) if an adequate amount of residue (4 to 6 t/ha) is left on the surface.

On the other hand, Hudson (*13*) in Rhodesia and Roose (*34*) in Ivory Coast found exponents larger than 2 for various tropical soils that are poorly covered. Wischmeier and Smith (*42*) estimated that a second degree fits better than a logarithmic function.

The influence of slope length being variable, participants in a workshop at Purdue University finally adopted, for current usage, the exponent 0.5 to express the influence of slope length on soil losses. The equation linking erosion to slope is written:

$$SL = \frac{\sqrt{\lambda}}{100} (0.76 + 0.53\ s + 0.076\ s^2) \qquad [5]$$

where λ is the slope length in feet and s is the steepness in percent.

At Adiopodoumé, on bare soil and averaged over five years, results similar to those of Wischmeier and Smith's theoretical curve have been found, but these results vary considerably from year to year (*28*). Under cultivation, the results vary greatly as a function of the percent of soil covered and cultural techniques (Table 3). At Séfa in Senegal (*19*), it appears that very slight variations in the slope (0.5%) are sufficient to lead to notable variations of erosion and runoff (Table 3). At Bénin, Willaime and associates (*40*, *41*) observed that the influence of slope length on erosion is not constant, nor very important. This uncertain influence of slope length on splash and rill erosion brings back into consideration the effectiveness for African conditions of antierosive techniques, such as terraces, banks, and diversion ditches that are too often blindly used in a variety of climates (*29*).

From a scientific point of view, this topographic factor is surely the weak point of the universal soil loss equation because the influence of slope is not independent of vegetal cover, cultural techniques, soil, and probably of climate (*28*, *34*). However, while waiting to have sufficient data available, one can rely either on this topographic index of Wischmeier or an exponential equation of the type ($SL = \lambda^{0.5} \times s^{1.5 \text{ to } 2}$). Both are satisfactory in a large number of practical cases, at least on non-swelling clay soils (*13*, *28*).

Vegetal Cover and Cultural Techniques, Factor C

This is by far the most important conditional factor. In fact, as long as the vegetal cover is uninterrupted, whether it is a matter of forests, bush,

Table 5. Erosion (t/ha/year) and runoff (% of annual precipitation) from various slope percentages in West Africa.

		Erosion			Runoff			
Stations	Slope	Natural Environment	Bare Soil	Cropped Soil	Natural Environment	Bare Soil	Cropped Soil	Source
		m t/ha/yr			% of annual rainfall			
Adiopodoume	4.5	–	60	–	–	35 [98]	–	*(28)*, *(36)*
	7%	0.03	138	0.1 to 90	0.14	33 [95]	0.5 to 30[87]	
	20%	0.1	570	–	0.7[12[a]]	24 [76]	–	
	65%	0.20 to 1	–	–	0.6 to 2.2(16)	–	–	
Anguedudou	29%	–	–	0.6 to 0.3	–	–	0.3 to 0.9	*(23)*
Azaguie	14%	0.5 to 0.7	–	0.9 to 4.6	0.4 to 4	–	5 to 10	*(36)*
		Md[b] 0.155	–	Md = 1.83	Md = 1.9	–	Md = 7	
		–	–	–	Max = [31]	–	Max = [74]	
Divo	9%	0.5	–		1	–	–	*(21)*
Bouake	4%	[c]b.0.20	18 to 30	0.1 to 26	b.0.3[16]	15 to 30	0.1 to 26	*(27)*, *(1)*
		n.b. 0.01			n.b. 0.03			
Korhogo	4%	b. 0.1 to 0.2	3 to 9	–	b. 5[50]	35	–	*(32)*
Ouagadougou	0.5%	b. 0.15	10 to 20	0.6 to 8	b. 10[50]	40 to 60[70]	2 to 32[60]	*(6)*, *(30)*
		n.b0.01			n.b. 2.5[10]			
Sefa	1 to 2%	b. 0.02 to 0.50	30 to 55		b. 0.3 to 1.5	25 to 55	8 to 40	*(19)*, *(5)*
		n.b. 0.02 to 0.20		2. to 20	n.b. 0.1 to 1.2			
Cotonou	4%	0.3 to 1.2	17 to 27.5 after land clearing	10 to 85	0.1 to 0.9	17	20 to 35	*(28)*, *(38)*
					[2.5]	[69]	[70]	
Boukombe	3.7	–	–	0.2 to 1.6	–	–	1 to 12	*(38)*, *(40)*
							Max [75]	
Allokoto	3.0	–	–	0.10 to 18.5	–	–	1 to 22 Max [70]	*(7)*

[a]The numbers in brackets represent the maximum coefficients of flow during a unit rainfall of 10-years frequency.

[b]Md = Median.

[c]The notations b and nb signify "burned" or "not burned."

savannah, and pastureland, or of a simple mulch, erosion and runoff are small despite the erosivity of the rainfall, slope steepness, and soil instability (Tables 4 and 5). The burning of savannah, especially if it is late in the dry season, significantly increases runoff and its solid content (*30*). But when the soil is totally denuded, erosion becomes catastrophic: Soil losses are multiplied by 100 to 1,000 and the flow by 20 to 50. Under cultivation, erosion is intermediate and varies to a large degree according to the type of crop, the rapidity with which it covers the soil, and the cultural techniques put into use to encourage its growth. Density and earliness of planting, cultivation of the soil, appropriate fertilization, and return of residues play a predominant role.

Factor C of the Wischmeier equation expresses the combined influence of the vegetal cover and cultural techniques on solid transport. It is calculated for each characteristic crop-stage period (5 in the United States and up to 8 in the humid tropical zone with two cultural cycles). Taking into account only the mean annual value, Table 6 presents those values that have been obtained for factor C in West Africa.

The use of factor C is capable of helping to define the cultural techniques best suited to each crop and the rotation to use in order to take into account regional ecological conditions.

Erosion Control Practice, Factor P

Buffer strip cropping and natural or artificial mulching alone could be the subject of small plot studies. These studies could help solve certain problems of soil and water conservation (Table 7).

Buffer Strip Cropping. By alternating on a slope cultivated in parallel

Table 6. The vegetal cover factor and cultural techniques (C Factor) in West Africa.

Cultural Techniques		Annual Average C Factor
Bare continuously fallowed		1
Forest or dense shrub, high mulch crops		0.001
Savannah, prairie in good condition		0.01
Over-grazed savannah or prairie		0.1
Crop cover of slow development or late planting - first year		0.3 to 0.8
Crop cover of rapid development or early planting - first year		0.01 to 0.1
Crop cover of slow development or late planting - second year		0.01 to 0.1
Corn, sorghum, millet (as a function of yield)		0.4 to 0.9
Rice (intensive fertilization)		0.1 to 0.2
Cotton, tobacco (second cycle)		0.5 to 0.7
Peanuts (as a function of yield and the date of planting)		0.4 to 0.8
1st year cassava and yam (as a function of the date of planting)		0.2 to 0.8
Palm tree, coffee, cocoa with crop cover		0.1 to 0.3
Pineapple on contour (as a function of slope)	burned residue	0.2 to 0.5
	buried residue	0.1 to 0.3
	Surface residue	0.01
Pineapple and tied-ridging (slope 7%)		0.1

strips (20 to 50 m wide) with narrow strips (2 to 4 m) permanently covered with grass, the landscape is rapidly transformed into a succession of fields of gentle slopes separated by grass-covered embankments. Due to fine roots and to numerous grassy stems, the strips absorb a large part of the flow (10 to 60% at Adiopodoumé) and cause the deposit of eroded soil in the upstream area (70 to 90% at Adiopodoumé) (*22*). Embankments of 50 cm formed naturally in five years following alluvial deposits in buffer strips have been observed at several locations in Ivory Coast. In the Sahelien zone where the grasses have difficulty protecting soils from the first rains, Delwaulle (*7*) has shown on large plots (4,000 m^2) that ridges of earth and low dry stone walls are slightly more effective than grass buffer strips. These methods further permit the determining of a guide from which it will be possible to move from an extensive nomadic agriculture to intensive stabilized cultivation while progressively modifying the topography (*22*, *33*).

A straw mulch several centimeters thick is as effective as a dense secondary forest 30 meters high (*28*,*35*) in absorbing kinetic energy of rainfall and maintaining erosion (0.03 t/ha/year) and runoff (0.5%) within acceptable limits. Given the difficulty of procuring the enormous vegetal quantities necessary to cover large industrial plantings, one must consider either leaving the maximum crop residue on the soil surface or using soil conditioners.

Artificial Mulch. By spraying a thin permeable film of polyvinyl acetate (Curasol supplied by Hoechst) at 60 grams per liter per square meter after plowing, soil losses have been reduced from 40 to 90 percent and the flow from 25 to 55 percent of the check. The spraying of this type of permeable plastic, mixed with grass seeds and fertilizers, is a future practice for protection of scalped industrial zones, road embankments, and channels. However, it is still too expensive for ordinary agriculture (*35*).

Cultural practices (maximum soil cover through early and dense planting, use of fertilizer, optimum working of the soil, mulch, plant covering, rotation, etc.) are much more effective in humid tropical zones than mechanical techniques (terraces or diversions) that are costly to build and difficult to maintain. The latter, however, are the practices mentioned most in soil conservation manuals all over the world and most of the time are recommended without preliminary study of adaptation (*22*, *25*, *28*, *29*).

Discussion and Conclusions

More than 500 annual measurements of erosion on experimental plots have been completed in West Africa. This allows us today to evaluate and to put into practice the universal soil loss equation (*44*).

It is well to recall, first, that this equation aims at predicting sheet and rill erosion in hilly areas, excluding mountains, where energy from runoff

Table 7. P factor for conservation practices in West Africa (*7*, *28*).

Conservation Practices	P Factor
Tied-ridging	0.20 to 0.10
Antierosive buffer strips from 2 to 4 meters width	0.30 to 0.10
Straw mulch	0.01
Curasol mulch (60 $gr/1/m^2$)	0.50 to 0.20
2-3 years of temporary grassland	0.5 to 0.1
Reinforced ridges of earth or low dry stone walls (ridge elevation : 80 cm above channel) + tillage + cultivation and balanced fertilization.	0.1

and linear erosion (mountain, stream and river) predominate and where the rainfall has very different characteristics. It neither approaches the problem of flow nor that of transport in solution and neglects the qualitative aspect of eroded materials. But the fertility factors of a large number of tropical soils are found stored in the first 20 centimeters (especially under forest conditions), and sheet erosion selectively removes the organic and mineral colloids as well as the nutritive elements that assure the chemical and water reserve of the soil (*19*, *20*, *28*).

Secondly, since this empirical equation is based on the statistical analysis of a large number of results, it is important to have numerous replications in space and chiefly in time to evaluate locally the value of the different coefficients to use.

Finally, since the data come from plots of limited area, it is difficult to use these results to predict regional values of sediment transport on large watersheds.

Realizing this, it is necessary to recognize not only the practical utility of this equation on the land to optimize the management of agricultural land, but also an evident scientific interest to define the relative influence of each of the factors under consideration. This equation fulfills its purpose, which is to determine the antierosive techniques to put into practice in each particular case of soil management. On the ancient African continent, its use seems to be perfectly acceptable and justified by a mass of results related to soils and to the slopes most currently cultivated in West Africa.

The erosivity index accurately takes into account the interactions of amount, intensity, and duration of rainfall on solid transport; there could, however, be added to it an "antecedant soil moisture index" expressing this condition before the rain. The analysis of thousands of rain gauge charts has allowed us to present a first approximation of the spatial distribution of the annual mean erosivity index. However, the question must be asked whether it is better to base the erosion control system on the mean erosivity of rain or on the hazard of a 10- or 100-year-frequency rainstorm.

The soil cover resulting from plants (and stones) has an importance that exceeds that of all the other factors determining erosion. Plant architecture as well as tillage practices play only a secondary rôle once the soil is 90 percent covered; however, the cultural antierosive techniques are very helpful in all the cases where the soil is sparsely covered. Index C allows, in addition, the selection of practices and crops best adapted to local ecological conditions.

Contrary to an opinion widely held among agronomists, ferrallitic soils and, to a lesser degree, ferruginous tropical soils, especially if they are gravelly, seem less erodible than a large number of leached soils of temperate regions. It is the special erosivity of tropical rainfall that leads to the severe erosion damage seen in tropical zones when the soil is bare. The soil erodibility nomograph proposed in 1971 (*45*), which permits the estimation of the index of the resistance of soils to erosion, seems applicable; however, a moderating coefficient should be added to take into account the gravel or rocky debris present in the tilled surface.

If the universal soil loss equation seems to be correctly applied to those clay soils that are predominantly kaolinitic, the most widely occurring and cultivated in West Africa, one must be very cautious where swelling clay soils are concerned (dark brown soils, vertisols, etc.). The work of Heusch's group (*12*) in Morocco demonstrates that the vertisols on the marls of the Rif react very differently.

The topographic factor and in particular the slope length certainly constitutes the weak point of this equation, since it varies with the soil type, cultural technique, and the vegetal cover. But while waiting to gather a sufficient amount of data under natural or simulated rainfall, it can be used in the majority of cases. Let me note, however, the importance of this caution for the choice of erosion control techniques that are often based on limitations of slope length. Consequently, the antierosive techniques of the biological type, that is to say cultural practices favoring soil cover, are at the same time the most efficient, the cheapest, the least difficult to use; and they are the best adapted to the conditions of the hills and plains of the ancient African continent.

To be of maximum use in West Africa, data is needed to modify the Wischmeier-Smith equation for soils with swelling clays; for mountainous regions of recent origin, where gully erosion predominates; and for Saharien and Mediterranean zones, where unusually intense rains are important. However, this equation seems to me to be well adapted to the majority of cultivated soils in West Africa and to the moderate slopes on ferrallitic and ferruginous tropical soils in particular.

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