APPROACH TO THE DEFINITION OF RAIN EROSIVITY AND SOIL ERODIBILITY IN WEST AFRICA

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SUMMARY

After 20 years of research on erosion and soil and water conservation in West-Africa, accurate data are collected on rain aggressivity and erodibility of some ferrallitic and ferruginous tropical soils (ultisols, alfisols). These although incomplete data enabled to apply the USLE equation in these developping areas. In order to extend this application to other situations, new research orientations are proposed based on rainfall simulator use.

RESUME

Après 20 années de recherches sur les phénomènes d'érosion et les méthodes de lutte antiérosive en Afrique de l'Ouest, des données précises ont été accumulées localement sur l'agressivité des pluies et l'érodibilité de quelques sols ferrallitiques et ferrugineux tropicaux. Ces résultats partiels permettent déjà l'application de l'équation de prévision de l'érosion de Wischmeier dans ces pays en plein développement mais doivent maintenant être étendus rapidement à d'autres situations; pour ce faire, de nouvelles orientations de recherche sont proposées qui font intervenir l'usage de simulateurs de pluie.

Introduction

Rainfall erosion is the interaction of erosivity, that is the potential ability of rains to cause erosion, and the erodibility of the soil. In this paper we like to explain briefly how the French overseas research institutes(1) tried to approach the problems of climatic aggressivity and soil erosibility in West-Africa where data are few and to propose new orientations for further research on this subject in West-Africa.

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(1) ORSTOM = Office de la Recherche Scientifique et Technique Outre-Mer,
Gerdat = Groupe d'Etude et de Recherche en vue du Développement de l'Agronomie Tropicale.

1. Rainfall erosivity

Every soil movement needs energy. With regard to rainfall erosion, there are simultaneously the kinetic energy of raindrops which destroy the aggregates on the top of the soil, and the runoff which carries out detached particles. On the old eroded surfaces of the African shield, as on the American Corn Belt, it is the impact energy of raindrops that is the main erosion source. But when the slope is increasing, runoff also becomes itself an abrasive agent and its energy may exceed that of raindrops if the slope steepness exceeds sixteen percent (WOODRUFF, 1948).

The studies on runoff plots with natural or simulated rainfalls emphasized three complimentary ideas :

a) raindrop energy causes a splash crust which modify the infiltration process and increases the importance of the runoff on the fields,
b) the rainfall intensity determines, in most cases, the proportion of rain that cannot infiltrate into the soil. This runoff starts as a thin trickle of water and picks up energy if the slope is steep and long enough,
c) the notion of a threshold value and duration below which erosion does not occur : a threshold of minimum intensity explained in the erosivity index developped by HUDSON (1973) and a threshold of duration of high intensity and a duration of the rainfall which causes soil saturation and the disintegration of the soil structure.

Figure 1 (from rainfall simulator trials on bare plots of ferrallitic sandy soils) shows well that with high intensity (120 mm/h), runoff starts only after a few minutes and increases with increase in soil moisture and soil structure degradation . The concentration of solid material reaches a first maximum at the beginning of the runoff when this carries away particles detached but not removed by preceeding rainfalls, and a second maximum when the splash crust is liquefied after a certain duration and energy of the rainfall.

These three parameters (energy, intensity and duration) are included in the rainfall index (R) of WISCHMEIER and SMITH (1960), and many researchers tried to analyse their accordance, distribution and relation to soil loss. We show already (Ibadan, 1975; Purdue 1976) how, in West-Africa, it is possible to simplify the computation of recorded raingauge charts. Kinetic energy can be substituted by the rainfall amounts which are strictly correlated (CHARREAU in Sénégal, 1969; GALABERT, MILLOGO et PIOT in Upper-Volta in 1972-1974; DELWAULLE in Niger, 1973; LAL in Nigeria, 1975 and AALDERS in Bénin, 1976).
($R = 0,0157\ H \times I_{30} - 1,179$) (CTFT, 1974).

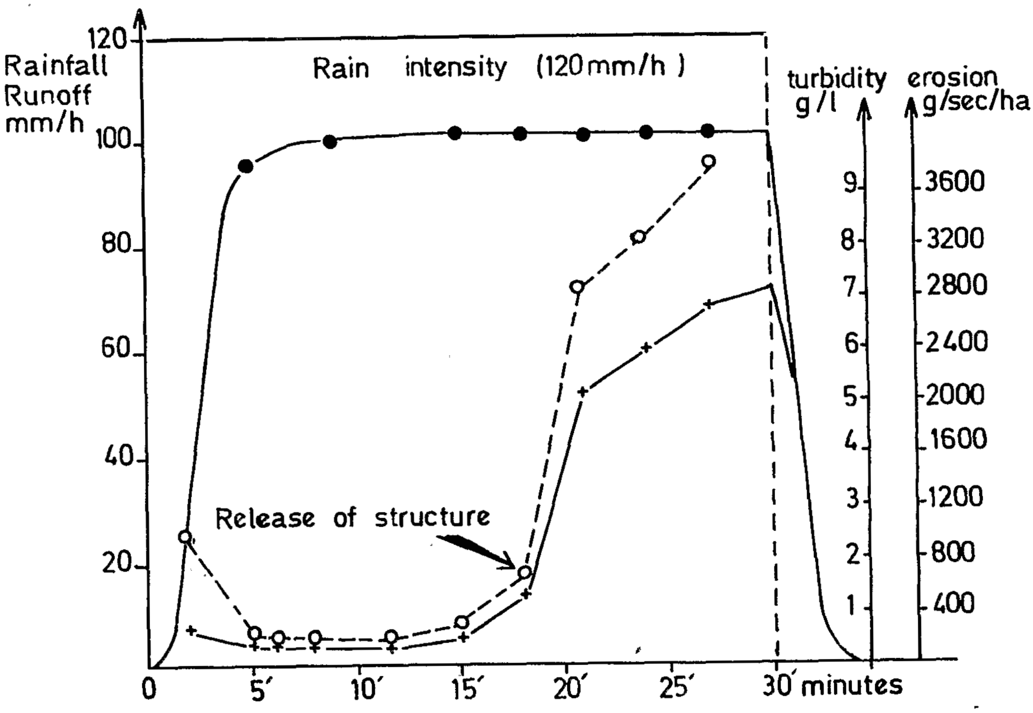

Figure 1 : Runoff, turbidity and erosion during a simulated rainfall.

Nevertheless, to study spatial distribution of the R-index we need valuable mean values established over more than 20 years. There is a difficulty of having only very few recorded data on rainfall intensity and where we have it, the recorder has been working only a very short time. Meanwhile, we have in West-Africa a relatively dense network of measuring stations of the amount of daily rainfall during 20 to 50 years which allows the calculation of representative averages. We therefore have studied in detail the connection between the amount of daily rainfall and the index of rainfall erosivity (R). The results show that (ROOSE, 1973) :

- there is a linear regression ($R = 0.577\ H - 5.766$) between the R-index and the rainfall amount (H) for rainfall of Monsoon type that is sustained rainfall during the month of June to August,
- there also exists a curvilinear regression for short duration high intensity rainfall very similar for all stations studied between the rainy forest of Abidjan to Sahelian savannah of Ouagadougou in Upper-Volta.

From long series of daily rainfall observations it is possible to find satisfactory monthly and yearly averages of the rainfall erosivity index.

It has been stated therefore that a simple empirical relationship exists between the yearly average erosivity index (Ram) over 5 to 10 years and the corresponding annual average of rainfall amount (Ham).

$$Ram/Ham = 0.50 \pm 0.05$$

This rate has been verified at twenty recording stations in West-Africa from Ivory Coast to Niger and from Senegal to Tchad, with the exception of stations located around the mountains and near the seaside. This relationship has permitted us to sketch the distribution of this index in Ivory Coast (1973), Upper-Volta (1974) and for whole West-Africa (1972) (figure 2).

This sketch must be considered as a working document sufficiently accurate for application of the USLE-equation but it must be corrected with new data on long duration climatic measurements. This sketch shows that the rainfall erosivity is very high in the humid tropical regions and decreases almost parallel to the isohyets between Abidjan (Ham = 2100, Ram = 1200) and Ouagadougou (Ham = 830, Ram = 430). This has not always been well accepted by geographers who often confounded the erosivity potential of an area with the interaction between the climatic aggressivity and the development of the plantcover.

This map of erosivity distribution assumes that the rainfalls are of the same type in all these zones. Further it is no longer necessary to include both the intensity of the rainfall and the amount in order to evaluate the average rainfall erosivity. This is explained by the correlation existing between the annual average precipitation in this region, the amount of the ten year rainfall and the "intensity x duration" curves (BRUNET-MORET, 1963-1967).

2. Erodibility of tropical soils

Soil scientists and agronomists know that some soil types are more resistant than others to the rainfall aggressivity. So people like CHARREAU and FAUCK (1970) in Senegal, COMBEAU and QUANTIN (1962) in Central-Africa, MARTIN in Congo, DE BLIC and MOREAU in Ivory-Coast have shown that after clearing the forest the aggregate stability decreases rapidly, then stabilises at a lower level under crops. At the same time the infiltration rate of the plough horizon decreases, and the rate of decrease is a function of the soil type, crops and cultivation techniques.

Some researchers tried to compare the splash resis-

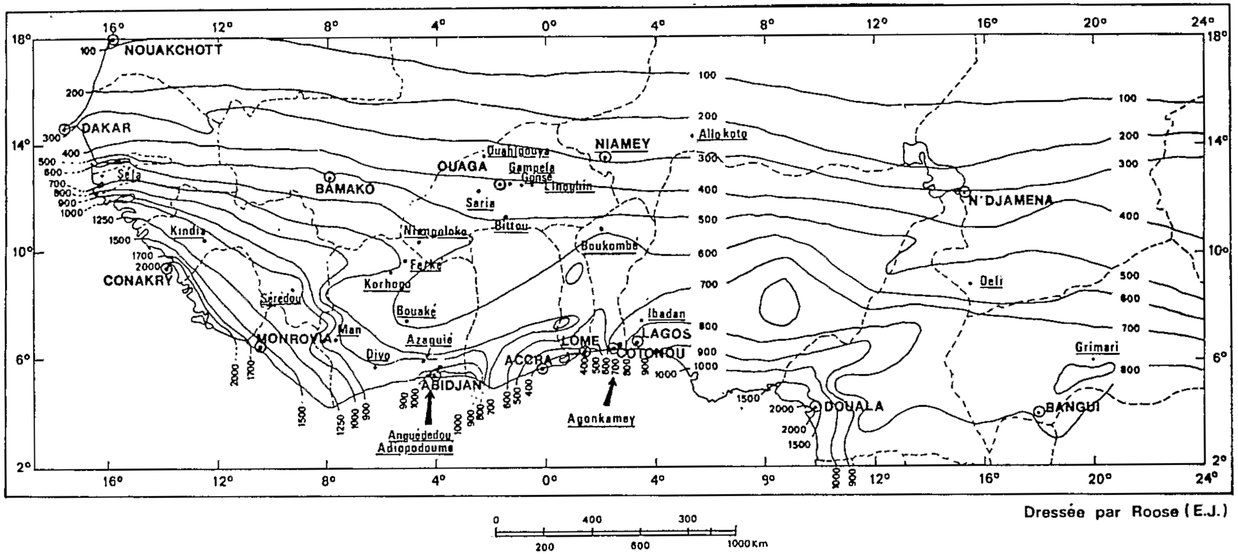

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Figure 2 : Mean annual erosivity index (R_{USA}) in Western and Central-Africa. Location of runoff plots.

tance of dried and sieved soil samples (HUDSON, 1973; COMBEAU and QUANTIN, 1962; NGO CHANG BANG, 1967; LAL,1977..) but it seems that no single laboratory test on sieved samples can give a good estimation of the soil erodibility, which is depending partly on splash resistance and also on shearing resistance when rill erosion occurs after a certain length of slope.

Therefore, we installed at many stations the standard runoff plots similar to those defined by Wischmeier : a bare cultivated fallow plot, 75 feet long and 9 % slope, with organic matter destroyed. The standard conditions must be modified because in Africa the length and the steepness of the slope are characteristics of toposequences and many erodible soils never get 9 % of slope; moreover, soil losses are much different from one year to another in relation with rainfall and cultivation period. The erosion factors which are generally exposed separately are not independant in nature.

So, we selected steep but characteristic slopes for each soil and landscape type and we corrected the soil losses with the help of the topographic factor of Wischmeier.

The results of about 50 annual data show that ferrallitic soils are very resistant (K = 0.02 to 0.20) and ferruginous tropical soils are much less resistant after 3 years of cultivation (K is increasing from 0.03 to 0.20-0.30). The nomograph of WISCHMEIER, JOHNSON and CROSS (1971) give similar results except for gravelly soils which need a correction factor for gravel and rocky debris that may act as a natural protective mulch. Their role in the protection of tropical soils is very important (DUMAS, 1965; SEGINER, MORIN, SHACHORI, s.d.). At Korhogo for example, not only the K-value is very low (K = 0.02) but it diminishes proportionately as the gravel concentrates in the upper horizon.

Table 1 : Erodibility of various tropical soils.

		K-value
- ferrallitic soils :	- from tertiary sand	0.05 to 0.10
	- from granite	0.10 to 0.15
	- from schist	0.15 to 0.20
	- gravelly	0.01 to 0.03
- ferruginous tropical soil from granite :		
	- after clearing old fallow	0.03 to 0.15
	- after 3-4 years of cultivation	0.20 to 0.30

It is important to note that K-values vary widely with seasons (K is higher during rainy periods) and from one year to another year : after clearing the fallow, the K-value is increasing during 3 to 5 years of cultivation before it levels off. So it is necessary to indicate the organic matter content of the soil at the moment its erodibility is measured or determined. The K-value is also varying with the length and perhaps with steepness of the slope and this variability is different from one soil to another.

So the K-value determination needs at least 5 years, a period too long for establishing the map of erosion hazards. To remedy these difficulties, ORSTOM has built in Ivory Coast a strong rotating rainfall simulator (SWANSON, 1965). It can irrigate a circular surface of 200 m^2 on which two runoff plots of 5 by 10 meters are insolated. One of the plots is treated as a bare fallow according to the method of Wischmeier; soil losses are corrected by the topographic factor of Wischmeier.

This simulator is used simultaneously for agronomic, pedologic and hydrological purposes. The program includes three rainfalls of 60 mm/hour on dry, wet and very wet soils (like in USA) and then a dozen rainfalls of duration (30 to 120 min.); intensity (30-60-90-120 mm/hour) and soil moisture variables (Ta = 1 hour to 1 week between 2 rainfalls). Three to six stations of the same toposequence are treated simultaneously during one month where the plots receive about 600 millimeters of rain.

At Adiopodoumé, LAFFORGUE, VALENTIN and ASSELINE (1977) applied twelve simulated rains (R-index : 485 foot.tons/acre.inch) on runoff plots of bare ploughed soil (after pasture) with 6.5 % slope in order to study the influence of slope length on runoff and soil losses.

Table 2 : Erosion and K-values of a sandy ferrallitic soil (very permeable) in relation to slope length of the plot (1977).

Slope 6 % Length slope (m)	Erosion Tm/ha	Topographic index (SL)	Erodibility index $K = \frac{A}{R \times SL \times 2,24}$
1 m	8.044	0.13433	0.055
2 m	8.645	0.18997	0.042
5 m	11.265	0.30036	0.035
10 m	13.744	0.42476	0.030

On this sandy and very permeable ferrallitic soils, with the slope length increasing from 1 to 10 meters, soil losses increased from 8 to 13.7 t/ha. But if the topographic factor is included, the soil erodibility (K) decreases from K = 0.055 to 0.030. Erosion does not increase proportional to square rooth of the slope length : ($L^{0.5}$), but E = f ($L^{0.289}$).

In the same research station, an other simulator test experiment (ROOSE and ASSELINE, 1978) on runoff plots, bare for more than 5 years, shows that the average K-value on 36 simulated rainfalls, is about 0.08 but varied from 0.01 to 0.21 in relation to the rainfall characteristics, the moisture of the soil and the structure degradation.

Table 3 : K-value of a sandy ferrallitic soil in relation to the slope steepness and the simulator test; Adiopodoumé, November 1975.

Slope length (m)	Slope steepness (%)	Topographic factor (SL)	Erosion (Tm/ha)	R_{USA}	K_3 for 3 tests	K_{12} for 12 tests
10	4	0.2346	28.6	950.3	0.020	0.057
10	7	0.4693	140.2	1046.3	0.132	0.127
10	20	2.3920	364.7	975.9	0.086	0.070

Detailed analysis of the data shows that soil resistance is better when the soil is dry than on a saturated field. The structure of the top soil (which is like a memory of preceeding rain aggressivity) can modify seriously the final soil losses, because if the splash crust gets enough time to dry between two showers, the topsoil becomes more resistant to splash energy. We find here again the notion of threshold above which soil movement may be important.

3. Conclusions

Actually we dispose of numerous data concerning average climatic erosivity, their spatial and temporary distribution and also on erodibility of certain ferrallitic and ferruginous tropical soils which lack swelling clays. One can apply the equation of Wischmeier to organise the agricultural development of these areas.

But many problems remain to be investigated in detail :

1) About climatic erovisity we must calculate the 10 year or the 100 year daily erosivity index distribution because these are the exceptional events which are the base for evaluation of hydraulic work calculations and to guide the soil and water conservationist.

2) There are many data available but not utilized in West-Africa. But it seems now also necessary to begin complementary studies on rainfall characteristics (energy, intensity, exceptional storms) of seaside regions (which are already very much cultivated) and of mountain areas where the erosion hazard is greater.

3) Concerning soil erodibility, the investigations must be quickly extended to other types of soils particularly on vertisols and brown tropical soils which are rich in swelling clays.

4) In parallel,other ways must be explored like adaption of the Wischmeier nomograph to African soils conditions taking into account an aggregation stability test, a permeability test and the density of gravel and rocks in the plough horizon.

5) During mapping and soil survey, relations between pedologicaly mapped units and the reaction of the soil to the water dynamic (infiltration and aggregation stability) should be considered.

6) Finally, splash resistance tests must be associated with runoff plots data under natural and simulated rainfall in order to compare the classification of soil types in relation to splash and shearing stress resistance.

But it is not sure that we will get something better than a soil classification related to some well known references (long test on runoff plots under natural rainfall) as long as we do not know better the interactions between the different erosion factors and particularly the interaction between the soil and the slope characteristics.

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