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RUNOFF, SEDIMENT YIELD AND ERODIBILITY CHARACTERISTICS OF SOME SOILS OF CENTRAL EASTERN NIGERIA UNDER SIMULATED RAINFALL

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A b s t r a c t. Failure of soil conservation plans in the subsaharan Africa is partly due to the lack of data on soil erosion hazard. This necessitated studies of runoff, sediment yield and erodibility characteristics of ten soils from different parts of central eastern Nigeria that were evaluated with simulated rainfall. The aim of the study was to obtain information which will aid better soil management. Rainfall intensity of approximately 180 mm h^{-1} was applied for 60 min to the soils packed in 0.30 x 0.12 x 0.10 m micro runoff plots situated at a slope with 3% inclination. Dry and wet runs were used.

The soils varied in texture and are low in organic carbon (OC) and cation exchange capacity (CEC). Measured soil bulk density ranged from 1.20 to 1.80 Mg m^{-3}. Runoff amount for dry runs varied between 77.6 mm and 235 mm representing between 13.2 and 40.4% of total rain applied. Variation in water infiltration into the soils was attributed to the differences in particle sizes, OC, structural properties and dithionite-citrate-bicarbonate iron oxide (Fed) content. The overall soil loss due to splash was between 0.10 and 2.60 kg $m^{-2}h^{-1}$. Splash losses were higher in dry than wet run indicating that potential erosion hazard due to splash is higher at the inception than the end of rains. Sediment yield of between 0.46 and 9.64 kg $m^{-2}h^{-1}$ for dry run and between 0.25 and 3.96 kg $m^{-2}h^{-1}$ for wet run was obtained. These values were also related to clay dispertion index (CDI), dispertion ratio (DR), OC and Fed. Water-stable aggregates greater than 0.5 mm (WSA > 0.5 mm) were found to negatively relate with splash and sediment yield. The measured and calculated erodibility ratings did not agree with the ranking of the soils. However, such parameters as exchangeable sodium percentage (ESP), OC, Fed, DR and CDI could be utilized in the prediction of erodibility of these and similar soils.

K e y w o r d s: runoff, rainfall simulation, sediment yield, soil management, infiltration

INTRODUCTION

One of the reasons of soil conservation plans and strategies fail in most of the sub-saharan Africa is the lack of data and essential information on factors that influence soil erosion. Elwell [10] observed that frequent soil erosion disasters in southern Africa occur unpredictably. Much emphasis on soil erosion prediction in western Africa is placed on the erosivity of rainfall which thought to be high [28,31]. Limitation of this kind of prediction is that, although rainfall is of high intensity, the behaviour of soils and their characteristics within rainfall erosive units may differ considerably which distors prediction of erosion. Researchers have also tried to match soil erosion susceptibility to geomorphological patterns along the line of geological weakness. For instance Niger Techno [24] conducted a study on soil erosion problems of central eastern Nigeria and marked the area of weak cuesta landscape as highly susceptible to erosion. Ofomata [29] based his own erosion classes of this zone on weakness in geology and land configuration.

The closest predictions done in the sub-saharan Africa on soil erosion integrating the available environmental factors are those of FAO [12], Mbagwu and Salako [21] and

Stocking *et al.* [35]. Whereas Mbagwu and Salako [21] studied a small watershed in the southeastern Nigeria using the factors of Universal soil loss equation (USLE), Stocking *et al.* [35] employed the Soil estimation model for southern Africa (SLEMSA). The problem with predictions based on either computer models or map generated information is that they do not give accurate information on the degree or extent of soil erosion on the field. In most cases they tend to overestimate or even underestimate soil loss, resulting in catastrophic failures of soil conservation plans.

Apart from studies of Lal [19, 20] and Obi [25] none has tried to evaluate the magnitude of soil loss in either field or laboratory conditions. Bryan and De Ploey [6] showed that rainfall simulators can be used extensively in the field and laboratory research on soil erosion. Recently Romkens *et al.* [32] used it to study the relative differences in the infiltration of selected soils from Europe, North America and Asia. Different uses to which a rainfall simulator can be put to were discussed by Bryan [5] and Hudson [14].

The objectives of the study are (i) to evaluate the relative susceptibility of some soils of the central eastern Nigeria to water erosion, (ii) to obtain information on their runoff potential and their differential infiltration rate under the same rainfall characteristics, and (iii) to relate their capability to erode to some characteristics. The aim is to provide physical information on the soils for better management.

MATERIALS AND METHODS

Study area

The area from which soil samples were analysed is located between latitudes 5E38' and 7E07' North and longitudes 6E36' and 8E30' East. Annual bimodal rainfall ranges from 1250 to 2500 mm, with a dry season of about 3 to 4 months. Rainfall intensities are high, often ranging from 191 to 254 mm h^{-1} [28]. The region has high insolation, with uniformly high temperatures throughout the year. A maximum temperature of about 35°C is common in the area.

Geology of the area is underlain by sedimentary rocks derived from successive marine deposites of Cretaceous and Terttiary periods [13]. Details about locations, classification, vegetation/land use and parent materials of the soils used are presented in Table 1.

Field sampling

Two locations representing each of the five erosion hazard classes predicted by Igwe [15] were selected for the study. On the whole, ten soils were sampled and two categories of samples; disturbed and undisturbed soils were collected for the study. All the samples were collected at the 0-15 cm depth. The undisturbed soil samples were used for the determination of bulk density and the water-stable aggregates. The disturbed soils samples were air dried and passed through 2 mm sieve and used for determinations as described below.

Laboratory study

For the erosion studies a portable rainfall simulator was used. The rainfall simulator is similar to that described by Meyer and Harmon [23]. The simulator had dimensions of 0.30 x 0.12 m with 143 drop formers. The average drop size produced was 4.5 mm and set to rain at the intensity of 180 mm h^{-1}. The aim was to simulate a near modal intensity for the area under study. The micro plots packed with samples sieved through 2 mm mesh were packed to reflect their field bulk density. The microplots were of 0.30 x 0.12 x 0.10 m with the bottom packed with washed coarse sand to allow easy drainage. Each sample was replicated three times. These micro plots were inclined to about 3% slope to reflect their average field slope condition which varied between 1.5 and 4%. The drop height was 2 mm.

The packed soil samples in the micro plots were allowed to air dry after which two test rainfall at dry and at wet state were applied to each sample in the micro plots, with each lasting for 60 min. The aim was to simulate dry and wet seasons rainfall. At each test run, runoff water was collected every 5 min, while the sediments

Table 1. Taxonomic classification, vegetation/land use and parent material for the soils

Soil	Classification	Vegetation/Landuse	Parent material
Akili ozizor	Typic Endoaquents, fine loamy, mixed isohyperthemic	Fallow with rejuvenating shrubs.	Sedimentary alluvium
Osamala	Typic Endoaquepts, fine loamy, mixed isohyperthemic.	Aquatic grass species	Sedimentary alluvium
Ezillo	Plinthic Kanhaplustults, fragmental, mixed isohyperthemic.	Cultivated	Shale
Nenwe	Aquic Kandiustults, fine loamy, mixed isohyperthemic.	Fallow	Shale
Ifite ogwari	Plinthic Kandiustults, fine loamy, mixed isohyperthemic.	Gmelina spp. forest	Shale/alluvium
Umumbo	Aquic Eutropepts, loamy, mixed isohyperthemic.	Fallow	Shale/alluvium
Nteje	Kandic Paleudalfs, fine-silty, kaolinitic, isohyperthemic.	Secondary savanna	Sandstone
Nsukka	Typic Kandiustults, loamy, kaolinitic, isohyperthemic.	Fallow	Sandstone
Ukehe	Typic Kandiustults, loamy, kaolinitic, isohyperthemic	Fallow	Sandstone
Nanka	Arenic Kanhaplustults, loamy, kaolinitic, isohyperthemic.	Cashew plantation/ extensively gullied	Sandstone

were pooled and oven-dried to obtain the sediment yield. Splash was also collected and measured while infiltration rate was calculated from the difference between the quantity of water applied and that lost as runoff. Erodibility for each run was calculated using the relationships of Wischmeier *et al.* [37]:

$$A = R \cdot K \cdot LS \cdot CP \quad (1)$$

where: A - total soil loss (Mg ha^{-1}), R - erosivity factor (MJ mm ha^{-1} h^{-1}), K - erodibility factor (Mg h MJ^{-1} mm^{-1}), LS - slope factor (dimensionless), CP - crop and land management factor (assummed to be 1 in this study).

To obtain K therefore Eq. (1) was transformed as follows:

$$K = A / (R \cdot LS). \quad (2)$$

Particle size analysis was measured by the hydrometer method [8]. Organic carbon was determined by the Walkley and Black method as modified by Allison [2]. Iron oxide (Fed) was measured by the dithinite-citrate-bicarbonate (DCB) method [22]. Bulk density was determined by the clod method described by Blake [4]. Water-dispersible aggregates (WSA) were measured by the Kemper and Chepil [18] procedure and used to compute the mean weight diameter (MWD). The method described by Sowers [34] was used to determine the liquid and plastic limits. Dispertion rado (DR) was calculated as:

%Silt+Clay(water)/%Silt+Clay (dispersed) (3)

whereas clay dispersion index (CDI) computed as:

[%Clay(water) / %Clay (dispersed)]·100. (4)

RESULTS AND DISCUSSION

General characteristic of the soils

The soils vary in clay content. The values range between 100 and 460 g kg^{-1} with a mean value of 260 g kg^{-1} clay and a coefficient of variation (CV) of 30% (Table 2). Silt content of these soils is low, which is typical for soils of southeastern Nigeria [1,17,26]. The mean silt value for all the soils is 172 g kg^{-1} with a CV of 102%. This indicates that a wide variation in silt content exists within these soils. However, apart from the soils from Akili ozizor, Ifite ogwari and Umumbo, the values of sand are high with a mean of 568 g kg^{-1} sand and a CV of 42% (Table 2). The soils are mainly sandy loam, sandy clay loam, clay loam and clay.

Both organic carbon (OC) and the cation exchange capacity (CEC) of the soils are low. Whereas, the OC ranges between 5 and 31 g kg^{-1} with a CV of 50%, the CEC values are between 2.0 and 18.5 cmol(+)kg^{-1} (Table 2). The fertility status of these soils is low as a result of excessive leaching and erosion due to high rainfall [11]. This is also caused by the sandy texture and porous nature of the soils.

Table 3 shows some structural properties of these soils. Water-stable aggregates (WSA) > 0.5 mm are high while WSA < 0.2 mm are low indicating that in the soils most of the aggregate sizes occur within the > 0.5 mm range. Mean-weight diameter (MWD) ranges from 0.57 mm in Osomala soils to 1.80 mm in Nsukka soils. The indices of plasticity indicate that the soils are mainly on the lower range while the bulk

Table 2. Particle size-distribution, organic carbon, exchangeable sodium percentage (ESP), cation exchange capacity (CEC) and citrate- bicarbonate-dithionite extractable Fe (Fed) for the soils

Soil	Clay	Silt	Sand	Org. carbon	Fed	ESP	CEC	TC[a]
			(g kg^{-1})			(%)	(cmol kg^{-1})	
Akili ozizor	460	380	160	31	24	0.6	18.5	C
Osamal	220	160	620	11	17	1.0	9.0	SCL
Ezillo	100	120	780	11	3	1.6	4.5	SL
Nenwe	340	100	560	9	5	0.7	9.5	SCL
Ifite ogwari	280	560	160	16	22	0.4	20.5	CL
Umumbo	340	300	360	13	7	1.2	8.5	CL
Nteje	140	40	820	5	5	3.5	2.0	SL
Nsukka	220	20	760	19	3	1.6	4.5	SCL
Ukehe	220	20	760	12	5	2.5	4.0	SCL
Nanka	280	20	700	10	2	1.5	4.0	SCL
Mean	260	172	568	13.7	93	1.46	8.5	-
CV %	38	102	42	50	85	61	71	

[a]TC - textural class, C - clay, SCL - sandy clay loam, SL - sandy loam, CL - clay loam.

Table 3. Structural properties[a] of a soil

Soil	WSA 1	WSA 2	MWD	PL	LL	PI	BD	DR	CDI
	(%)		(mm)		(%)		(M gm^{-3})		
Akili ozizor	67.6	29.2	1.61	19.04	38.89	19.85	1.52	0.74	45.3
Osamal	44.4	27.6	0.57	8.11	16.28	8.17	1.32	0.62	18.2
Ezillo	47.6	47.2	1.46	22.37	42.37	20.0	1.43	0.59	15.0
Nenwe	66.8	25.2	1.23	14.94	23.66	8.71	1.82	0.37	31.3
Ifite ogwari	86.0	6.4	1.87	17.65	29.57	11.92	1.61	0.64	31.0
Umumbo	31.2	52.4	1.12	24.07	33.33	9.26	1.30	0.94	21.4
Nteje	73.2	7.2	1.42	7.70	51.52	43.83	1.54	0.13	9.0
Nsukka	75.2	13.6	1.80	4.20	16.28	12.08	1.20	0.35	11.1
Ukehe	76.8	10.4	1.73	3.01	9.90	6.89	1.47	0.24	8.6
Nanka	71.6	23.2	1.10	10.48	17.65	7.17	1.32	0.24	18.8

[a]WSA 1 - water-stable aggregates >0.50 mm, WSA 2 - water-stable aggregates <0.20 mm, MWD - mean-weight diameter, PL - plastic limit, LL - liquid limit, PI - plasticity index, BD - bulk density, DR - dispersion ratio, CDI - clay dispersion index.

density is moderate to high with values ranging between 1.20 and 1.80 Mg m^{-3} (Table 3). These values are within the range of similar soils discussed by Obi and Asiegbu [26], Obi *et al.* [27].

Runoff and infiltration

Runoff amount for the soils differed significantly. The highest value of 235.6 mm (or 40.4% of the total simulated rainfall) was obtained in the dry run for Akili ozizor soils, while the least value of 77.6 mm (or 13.2% of simulated rainfall) was recorded for Nenwe soils (Table 4). In the wet run the highest value was obtained in Osamala soils with 226.1 mm (or 38.8% of the simulated rainfall). In an Alfisol of western Nigeria, Lal [20] recorded on unmulched plots of between 1 and 15% slope, 32 to 67% runoff. In the present study on a homogeneous slope with 3% inclination, the values for dry and wet runs fall within 11.8 to 40.4%. Soil rating in terms of susceptibility to runoff using the dry run, was as follows: Akili ozizor > Osamala > Umumbo > Nsukka = Ukehe > Nteje > Nanka > Ezillo > Ifite ogwari > Nenwe. With the wet run, the order was Osamala > Akili ozizor > Nsukka > Umumbo > Ukehe > Hanka > Nteje > Ezillo > Ifite ogwari > Nenwe. In both runs Ezillo, Ifite ogwari and Nenwe retained their positions. These discrepancies in the behaviour of the soils during wet and dry runs could be attributed to the initial sealing and crusting effects and the impact of antecedent soil water content. Chen *et al.* [7] indicated that this kind of variation in runoff values with time is as a result of runoff stages which start from initiation to steady state. The dry run could be regarded as initiation state while the values for wet-run runoff are the steady state.

Exchangeable sodium percentage (ESP) correlated significantly with dry-run runoff. Negative correlation coefficients were obtained between bulk density and runoff at both dry and wet runs ($r = -0.52$) (Table 5). This result confirms previous findings of Obi (25] and Obi *et al.* [27]. The relatively high correlation coefficient obtained between Fed and runoff (Table 5) and OC versus runoff for both dry and wet runs confirms the observations of Bisson- nais and Singer [3].

Table 4 also shows the relative values of final infiltration rates for the soils. The pattern followed that of runoff. Values for both dry and wet runs ranged from 59.3 to 67.3 mm h^{-1}. The values did not differ much between the dry and wet runs. Organic carbon correlated significantly with dry run steady state infiltration rate ($r = -0.61$) thus confirming the findings of

Table 4. Mean runoff amount, infiltration rate, splash, sediment yield and erodibilities of the soils

Soil	Runoff amount				Infiltration rate		Splash		Sediment yield		Erodibilities		
	R_D	R_W	R_D	R_W	R_D	R_W	R_D	R_W	R_D	R_W	K_W	K_{RD}	K_{RW}
	(mm)		(%)		(mm h^{-1})		(kg $m^{-2}h^{-1}$)				(Mg h MJ^{-1} mm^{-1})		
Akili ozizor	235.6	21.2	40.4	38.1	59.6	66.7	1.28	0.65	9.64	1.64	0.023	0.036	0.006
Osamal	221.3	226.1	37.9	38.8	61.0	59.3	2.60	0.82	8.20	0.97	0.023	0.030	0.003
Ezillo	122.0	109.5	20.9	18.8	65.3	66.1	1.40	0.71	2.43	2.52	0.038	0.009	0.009
Nenwe	77.6	68.9	13.2	11.8	67.3	67.2	1.25	0.10	0.46	0.69	0.010	0.002	0.003
Ifite ogwari	102.8	87.6	17.6	15.0	66.0	66.8	1.45	0.27	1.41	0.25	0.030	0.005	0.001
Umumbo	187.6	129.7	32.2	22.3	62.7	65.4	2.46	0.18	5.67	2.08	0.030	0.021	0.008
Nteje	156.5	114.4	26.8	19.6	64.5	65.5	1.06	0.12	2.20	1.23	0.050	0.008	0.004
Nsukka	171.5	168.1	29.4	28.8	63.2	62.7	1.66	0.44	5.40	3.96	0.040	0.020	0.015
Ukehe	170.8	122.5	29.3	21.0	62.8	64.9	2.21	0.72	4.26	3.64	0.045	0.016	0.013
Nanka	125.9	116.6	21.6	20.0	66.1	65.2	0.88	0.33	1.85	2.32	0.052	0.007	0.006

R_D - dry run, R_W - wet run, K_W - Wischmeier's erodibility factor, K_{RD} and K_{RW} are erodibility factors by dry and wet runs, respectively.

Bissonnais and Singer [3] who obtained significant negative correlation between both OC, Fed, and infiltration rates. In the present study Fed, though correlated with dry run infiltration state (r = -0.49), was not significant. Bulk density correlated highly (r = -0.62) with wet run infiltration rate thus indicating that at moist state high bulk density may retard the infiltration rate of the soils. Although neither WSA > 0.5 mm significantly correlated with dry run infiltration rate (r = 0.50) or MWD and PL with wet run infiltration rate (r = 0.52, 0.53) (Table 5), respectively, the trend is that the higher these parameters were, the higher the infiltration rate. From the results on the infiltration rates of the soils, it is observed that there are variations. These variations were reported by Römkens *et al.* [32] who attributed them to the differences in OC, particle sizes, swelling clay and Fed contents.

Splash and sediment yield

Dry run soil loss from splash presented in Table 4 ranges from 0.88 kg m^{-2} h^{-1} in the Nanka soils to 2.60 kg $m^{-2}h^{-1}$ in the Osamala soils. However, in the wet run, the trend changed with the Nenwe soils recording the lowest value of 0.10 kg m^{-2} h^{-1}, while the highest value of 0.82 kg m^{-2} h^{-1} was still obtained in the Osamala soils. The general trend is that in all cases the values for splash loss under dry run were higher than those of the corresponding wet run. The implication of the above is that under natural condition splash is higher during the inception than at the middle of the rainy season, suggesting that the hazards due to splash could be checked very early in the rain to avoid catastrophic situations. Although most of the factors and indices tested did not correlate significantly with either splash from dry or wet runs, the trend is that WSA > 0.5 mm have a negative relationship with splash obtained by dry run. This indicates that soil management practices should always aim at keeping the aggregates large. Liquid limits (LL) and plasticity index (PI) also show a negative relationship with dry run splash. This implies that soils with high shrink -swell hazard are difficult to break down by splash drops.

The sediment yields from the soils varied tremendously. The highest dry run sediment yield of 9.64 kg m^{-2} h^{-1} was obtained from Akili ozizor whereas 0.46 kg m^{-2} h^{-1} (which is the

Table 5. Correlation coefficients and level of significance relating soil properties to erosion parameters

Properties	Runoff amount		Infiltration rate		Splash		Sediment yield		Erodibilities		
	R_D	R_W	R_D	R_W	R_D	R_W	R_D	R_W	K_W	K_{RD}	K_{RW}
WSA 1	-0.34	-0.29	0.50	0.30	-0.56	-0.18	-0.36	0.02	0.28	0.36	-0.01
WSA 2	0.17	0.13	0.16	0.04	0.29	0.14	0.25	0.05	0.30	0.26	-0.09
MWD	-0.22	-0.31	0.12	0.53	-0.34	-0.09	-0.20	-0.32	-0.24	-0.20	-0.37
PL	-0.12	-0.18	0.08	0.52	-0.06	-0.17	-0.01	-0.39	-0.42	-0.01	-0.34
LL	-0.01	-0.14	0.02	0.47	-0.40	-0.30	-0.08	-0.37	0.04	0.09	-0.33
PI	0.06	-0.04	0.02	0.21	-0.44	-0.24	-0.10	-0.18	0.33	-0.10	-0.17
BD	-0.52	-0.52	0.21	-0.62*	-0.38	-0.35	-0.46	-0.64*	-0.50	-0.45	-0.59*
DR	0.36	0.32	-0.41	0.02	0.47	0.16	0.50	-0.26	-0.55	0.49	-0.18
CDI	0.07	0.14	-0.16	0.43	-0.23	-0.08	0.26	-0.55	-0.69*	0.26	-0.51
Clay	0.25	0.22	-0.31	0.30	-0.02	-0.17	0.39	-0.25	-0.55	0.40	-0.22
Silt	0.07	-0.05	-0.16	0.31	0.09	-0.07	0.19	-0.57	-0.46	0.20	-0.50
T. Sandy	-0.16	-0.13	0.24	-0.35	-0.06	0.12	-0.30	0.52	0.56	-0.30	0.46
Org. C	0.51	0.55	-0.61*	0.12	-0.01	0.34	0.66*	0.13	-0.30	0.67*	0.19
Fed	0.40	0.46	-0.49	-0.01	0.14	0.25	0.51	-0.57	-0.49	0.51	-0.52
ESP	0.59*	-0.14	0.04	-0.09	-0.10	-0.08	-0.20	0.40	0.74**	-0.21	0.35

*Significant at P>0.05, **significant at P>0.01.

least) was obtained from the Nenwe soils, (Table 4). The order of the sediment losses from these soils is, Akili ozizor > Osamala > Umumbo > Nsukka > Ukehe > Ezillo > Nteje > Nanka > Ifite ogwari > Nenwe. With the exception of the Ezillo and Nanka soils, relatively lower values were obtained when the soils are subjected to wet than dry run. The values are between 0.25 and 3.96 kg m^{-2} h^{-1}. In a field runoff trial at Nsukka on the 5% slope (one of the areas under study) Obi [25] obtained between 35 and 55 t ha^{-1} y^{-1} soil loss. Also in an Alfisol in western Nigeria, Lal [19] obtained a soil loss of 156 t ha^{-1} y^{-1} on a slope of 15%. In the present study, values obtained either in the dry or wet runs on a 3% slope were all below 10 kg m^{-2} h^{-1} (equivalent to 100 t ha^{-1}). The ranking of the soils using the wet run sediment yields is: Nsukka > Ukehe > Ezillo > Nanka > Umumbo > Akili ozizor > Nteje > Osamala > Nenwe > Ifite ogwari.

It will be observed that although clay content did not correlate significantly with either dry or wet run sediment yield, dispersion ratio (DR) relates with dry run sediment yield positively. Also clay dispersion index (CDI) shows a negative relationship with wet run sediment yield. This result confirms the earlier observation of Igwe *et al.* [16] that CDI predicts potential soil loss better than DR, MWD and WSA. Another important observation was the significant correlation of organic carbon (r = 0.66) (Table 5) with dry run sediment yield which is also in agreement with the findings of Igwe *et al.* [16]. The positive relationship of OC and sediment yield at dry run could be attributed to the hydrophobic nature of organic matter which also manifests in the runoff volume from the dry and wet runs. Piccolo [30] observed that water repellency and aggregate contractability mainly caused by organic material reduces potential slaking effects of rain drop impact and subsequent rill erosion risks and increasing runoff. Fed showed a non-significant relationship with sediment yield; however, the trend is that whereas high Fed content increases sediment yield at dry run, it tends to reduce it at wet run. Runoff and sediment yield obtained from dry run correlated significantly (r = 0.96) while the corresponding wet runoff and sediment yield recorded very low relationship (r = 0.16).

This indicates that sediment yield depends on runoff at the inception of the rains but as the rain progresses the soils becomes more compact and cohesive thereby exposing less soil for detachment by the runoff.

Evaluation of erodibility ratings

The erodibility ratings for the soils were calculated using Wischmeier's nomograph [38] and values obtained from dry and wet runs. The calculated erodibility (K_W) using the nomograph ranged from 0.01 Mg h MJ^{-1} mm^{-1} in Nenwe to 0.052 Mg h MJ^{-1} mm^{-1} in the Nanka soils. The rating of the soils is as follows: Nanka > Nteje > Ukehe > Nsukka > Ezillo > Umumbo = Ifite ogwari > Akili ozizor = Osamala > Nenwe. In this rating, soils with higher total sand fractions tend to erode more than those with finer fractions. However, CDI correlated significantly (r = -0.69) with the calculated erodibility while DR, clay, silt Fed and bulk density all showed high relationship with the calculated K_W. The most significant relationship (r = 0.74) occurred between ESP and K_W. Singer *et al.* [33] suggested the inclusion of ESP or SAR as one of the properties to predict soil erodibility.

The erodibility rating of the soils in the dry run did not follow the trend of the Wischmeier's erodibility values (Table 4). In this, soils with higher clay contents showed higher erodibility value, OC also correlated positively (r = 0.67) with erodibility at dry run. This trend is also a confirmation of a hydrophobic nature of organic matter, especially when the soil was still dry but such trend disappears when the soil imbibes more water and then the organic materials gradually start to absorb water. The absolute values of erodibility fall between 0.002 to 0.036 Mg h MJ^{-1} mm^{-1}. Obi *et al.* [27] obtained in similar soils, values of between 0.006 to 0.09 Mg h MJ^{-1} mm^{-1}. The dry run erodibility ratings of the soils are, Akili ozizor > Osamala > Umumbo > Nsukka > Ukehe > Ezillo > Nteje > Nanka > Ifite ogwari > Nenwe.

Table 4 also shows relatively low wet run erodibility values. The highest erodibility value of 0.015 Mg h MJ^{-1} mm^{-1} was obtained for the Nsukka soils while the least was 0.001 Mg h MJ^{-1} mm^{-1} for Ifite ogwari soils. The ranking of the wet run erodibility of the soils is, Nsukka > Ukehe > Ezillo > Umumbo > Nanka = Akili ozizor > Nteje > Osamala = Nenwe > Ifite ogwari.

One striking thing about all these erodibility ratings is that none agrees with each other. Wischmeier's K factor showed a low correlation coefficient (r = -0.23) with erodibility calculated from the dry run and with that calculated from the wet run (r = 0.42). This non agreement of the indices was also observed by Obi *et al.* [27]. According to them, the sequence of erodibility varied with prevailing soil conditions at the time of determination. Similar observation was made in the United States by Trott and Singer [36]. Although the erodibility indices did not agree, deductions could be made from their values about the relative susceptibility of the soils to runoff erosion.

Another point worth noting is the relationship of erodibility and some soil properties which were not hither-to included in the Wischmeier's nomograph. These properties are DR, CDI, Fed and ESP. El-Swaify [9] noted that the original predictive equations did not include a measure of the contributions of amorphous or oxidic constituents to structural stabilities, and thus, susceptibility to erosion. Singer *et al.* [33] further proposed a multiple regression equation that included among the known variables in prediction of erodibility, dithionite extractable iron and SAR.

The Wischmeier's erodibility value tends to over-predict the soil erodibility. Perhaps when all these factors are incorporated into the equation, a better predictive equation may be found for the erodibility of soils of humid tropics with high iron oxide content.

CONCLUSIONS

1. There are marked differences between runoff during dry and wet runs. These differences have been attributed to the initial sealing and crusting effects and the impact of the antecedent soil water content. ESP, Fed and OC are also found to affect runoff.

2. Splash losses were higher under dry run than the corresponding wet runs. Soil properties which influence splash were the liquid limits and plasticity index. Although clay content did not correlate significantly with sediment yield, such properties like DR and CDI correlated significantly with sediment yield during the dry runs confirms the hydrophobic nature of organic matter at the inception of the rains.

3. Finally ESP, Fed and DR were found to relate very well to erodibility, thus confirming the earlier proposal that these properties should be included in future erosion prediction models.

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