

Testing the applicability of a soil erodibility nomogram for some tropical soils

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ABSTRACT Soil erodibility measurements using field runoff plots were made for three contrasting soils in Nigeria. Field experiments were conducted over a period of 3 years from 1980 to 1983. The soil at Onne in eastern Nigeria is developed on coastal sediments and is classified as a paleudult. The soil at Ikom derived from basalt is a rhodustalf, and that at Jos on basement complex is an oxic paleustalf. Three runoff plots, each measuring 25 m x 4 m, with appropriate collection tanks and multidivisor system were established at each site. Rainfall intensity was monitored for each experimental site using a daily recording raingauge. Also monitored were the initial soil properties and their alteration over the 3-year period. Estimates of soil erodibility were made using the nomogram developed by Wischmeier et al. (1971). Field measurements indicate soil erodibility to be 0.015, 0.04 and 0.04 (in SI units) for Ikom, Onne and Jos soils, respectively. Soil erodibility as estimated from the nomogram is 0.039, 0.025 and 0.18 for Ikom, Onne and Jos respectively. The considerable differences between the measured and estimated values of soil erodibility indicate the necessity for appropriate modifications to adapt this nomogram for tropical soils.

L'applicabilité du nomographe d'érodibilité pour certains sols tropicaux

RESUME Des mesures d'érodibilité du sol ont été faites pour trois sols différents du Nigéria, sur des petites parcelles d'érosion. Ces expériences au champs ont été conduites sur une période de trois ans, de 1980 à 1983. Le sol à Onne dans l'est du Nigéria est dérivé de sédiments marins et classifié "paleudult". A Ikom, le "rhodustalf" s'est développé sur basalte et celui de Jos, un "oxic paleustalf" sur roche-mère basique. Trois parcelles d'érosion de 25 m sur 4 m, munies d'un système approprié de collecte et de partiteurs, ont été établies à chaque site. L'intensité de la pluie est déterminée à l'aide d'un pluviomètre enregistreur journalier. Les caractéristiques initiales du sol ont été relevées et leur changement suivi pendant la période de trois ans. Les estimations d'érodibilité sont obtenues par le nomographe développé par Wischmeier et al. (1971) Les mesures expérimentales indiquent des valeurs d'érodibilité

de 0.015, 0.04 et 0.04 (unités SI) pour Ikom, Onne and Jos respectivement. Les estimations du nomographs sont 0.039, 0.025 et 0.18 pour les sols de Ikom, Onne et Jos respectivement. Les différences considérables entre les valeurs mesurées et estimées indiquent la nécessité de modifications appropriées, pour l'adaptation de ce nomographe aux sols tropicaux.

INTRODUCTION

Soil erosion causes severe and extensive land degradation in the tropics. Ever increasing demand for food and other basic necessities, brought about by increasing population pressure throughout the developing world, necessitates continuous and intensified production even from marginally productive lands. This intensive land use further increases the risk of soil erosion. Consequently, FAO has initiated a major effort to assess the global extent of existing and potential soil degradation problems (Dudal, 1980).

In the humid tropics, erosion by water depends on the extent of disturbance of the natural protective cover by man. The low erosion rates under natural vegetation stand in marked contrast to the severe erosion occurring once the land is cleared for cultivation and exposed to intense rainfall (Greenland, 1977). Cultivated lands have little protection against rainfall erosion, particularly at the onset of the rainy season when the vegetation cover is sparse (Rapp, 1977). Roose (1977) reported soil erosion losses ranging from 0.02 to 1.2 t ha⁻¹year⁻¹ under natural cover to over 0.1 to 90 t ha⁻¹year⁻¹ for cropped soil and up to 3 to 570 t ha⁻¹year⁻¹ for bare soil. Similarly Lal (1976) reported average soil erosion losses of up to 99 t ha⁻¹year⁻¹ for bare fallow and up to 9.4 t ha⁻¹year⁻¹ for a maize-maize rotation.

In spite of these data, basic information concerning the extent and impact of erosion in the tropics for a wide range of soils with different ecologies is scarce. Also scarce is the information needed to quantify the causative factors and to formulate soil loss tolerance limits. The objective of this study was to obtain this basic research information for three soils and locations in Nigeria. Combined with an ongoing research experiment using a laboratory rainfall simulator, attempts have been made to quantify the factors that influence soil splash, detachability and transportability. Field measurements of soil erodibility have been compared with those obtained using the rainfall simulator and with those estimated from soil properties.

The use of the Universal Soil Loss Equation (USLE) (Wischmeier & Smith, 1978) for prediction of erosion requires site specific values of the parameters concerned. Little is known about the appropriate values of these parameters for tropical sites, making it difficult to evaluate the adaptability of this equation. In view of the high costs and long periods of time associated with direct measurement of soil erodibility, there is a need to adapt the nomogram method for estimating erodibility of tropical soils (Wischmeier et al., 1971). There are contradictory reports concerning the applicability of the nomogram for estimating the erodibility of soils in the tropics. This contradiction is not surprising given the wide

diversity of tropical soils. The range of parameters used in the nomogram is rather wide and there is a need to develop/adapt adequate techniques for predicting the erodibility of the wide range of tropical soils, based on easily and routinely measured soil properties.

MATERIALS AND METHODS

This study was conducted at the International Institute of Tropical Agriculture (IITA) as a part of a cooperative project involving IITA and the State University of Ghent. Field runoff plots were established at three locations in Nigeria: Ikom, Heipang (near Jos) and Onne near Port Harcourt. The experimental sites are shown in Fig.1 and a brief description of the locations and the soils is given in Tables 1, 2 and 3.

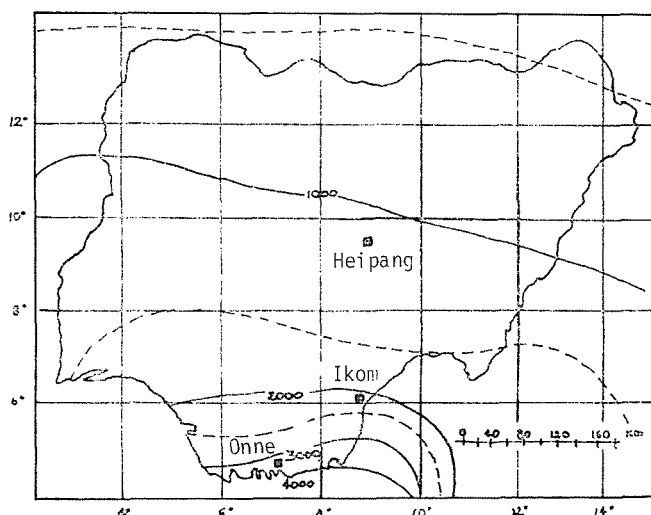


FIG.1 The location of the three sets of experimental plots established in Nigeria. The map also shows the mean annual rainfall (mm) for these areas.

Data collection from these plots started in April, June and November 1980 for the Ikom, Heipang and Onne sites, respectively. Runoff and soil loss measurements were taken on 25 m x 4 m runoff plots, established on slopes of 5% at Ikom and Heipang and 5.6% at Onne, respectively. The soil and water collection system is essentially a multi-slot sampling device, designed to sample the runoff and soil loss collected over a long period of about 1 month. The system consists of a runoff collection apron, 4 m wide, at the lower end of the plot, and a level approach channel which directs the total runoff to the first tank (1500 l) where most of the eroded soil is settled. This tank is connected to the first and second storage drums by pre-calibrated slot-samplers (Fig.2).

Three plots were established at Ikom and Heipang, and four plots at Onne (Fig.3). One plot in each location was mulched, and the others were maintained as bare fallow. The mulch treatment kept the

TABLE 1 Environmental characteristics of the experiment sites

Location	Latitude	Altitude (m)	Soil classification:		Parent material	Annual rainfall (m)	Number of raindays/ year
			FAO	Taxonomy			
Ikom	6°	150	Eutric Nitosol	Rhodustalf	Basalt	2200	165
Heipang	9°50'	1260	Ferric Acrisol	Paleustalf	Basement complex	1400	106
Onne	5°50'	30	Xanthic Ferralsol	Paleudult	Coastal deposits	2500	188

TABLE 2 Physical characteristics of the soils

Location	Mechanical analysis (%)			Penetrometer resistance (kg cm ⁻²)	Bulk density (g cm ⁻³)
	Sand	Silt	Clay		
	0.02-2 mm	0.002-0.02 mm	<0.002 mm		
Ikom	7.4	8.3	84.3	2.96	0.70
Heipang	79.8	6.2	14.0	3.35	1.39
Onne	87.2	2.6	10.2	1.54	1.30

TABLE 3 Chemical characteristics of the soil

Location	pH	Organic matter (%)	Total nitrogen (%)	Bray-P (ppm)	Effective cation exchange capacity (meq 100g ⁻¹)
Ikom	5.7	6.08	0.381	8.4	11.5
Heipang	-	0.88	-	-	-
Onne	4.8	2.29	0.069	56.4	2.9

soil completely covered with a layer of plant material collected from the surrounding fallow fields, and applied at the rate of approximately 6 t ha⁻¹. The bare fallow plots were regularly tilled to avoid surface crusting and weed growth.

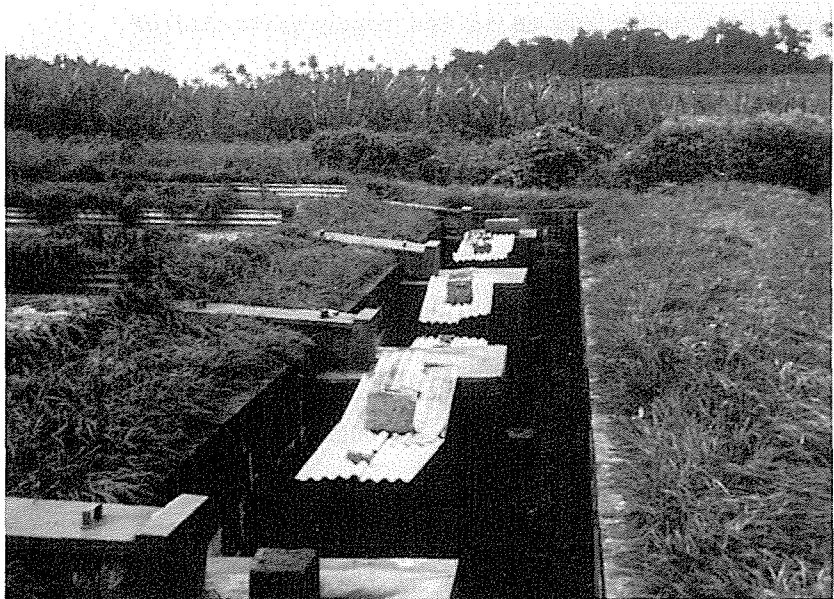


FIG.2 A runoff and sediment collection system consisting of an apron, a flume, and multi-divisor tanks.



FIG.3 A general view of the runoff plots at Onne.

Rainfall characteristics were monitored with a recording raingauge (Belfort Instrument Model 5-710). The soil erodibility factor (K) was calculated from the following equation:

$$K = \frac{A}{R \times LS}$$

where A is the observed soil loss in $t\ ha^{-1}$, R is the rainfall erosivity index and LS is the topographic factor.

RESULTS

Soil erodibility

The data on soil erodibility (Tables 4, 5 and 6) indicate the variability in the measured values of K for different rains recorded during a period of 1 year. This high variability is also indicative of the need for more replications. In spite of this high variability, it is obvious that the K values are low, when compared to the erodibility values of 0-0.55 for some tropical soils of Hawaii cited by El-Swaify & Dangler (1977). The cumulative erodibility factor K ranged from 0.049 for Ikom, through 0.069 for Heipang to 0.099 for Onne.

Soil erodibility increased with time after the establishment of the plots. A similar trend was observed by Lal (1981), who stated that soil erodibility is a time dependent function, and is influenced by deterioration of the soil structure and accumulation of the less erodible coarse fraction at the soil surface.

Changes in erodibility with time are represented in Fig.4, where in addition to the K and cumulative K values for different periods,

TABLE 4 Measured K values for field plots at Ikom

	Plot	Soil loss (A) (t ha ⁻¹)	Erosivity (R)	Slope-length factor (LS)	Measured erodibility (K):		Cumulative parameters:		
					Actual	Mean	Ac	Rc	Kc
5/6/80	1 (M)	0.03		0.506			-	-	-
	2	1.25	454	0.528	0.005	0.008	-	-	-
	3	2.28		0.501	0.010		-	-	-
11/8/80	1 (M)	0.24		0.506			-	-	-
	2	2.85	364	0.500	0.015	0.018	4.1	818	0.0095
	3	3.82		0.501	0.021		6.1		0.015
19/9/80	1 (M)	0.10		0.506					
	2	6.93	518	0.528	0.025	0.095	11.0	1336	0.016
	3	3.55		0.501	0.014		9.7		0.014
16/3/81	1 (M)	0.07		0.506					
	2	30.09	809	0.528	0.070	0.073	41.1	2144	0.036
	3	30.53		0.501	0.075		40.2		0.037
15/7/81	1 (M)	0.60		0.506					
	2	0.91	1026	0.528	0.002	0.003	42.0	3170	0.025
	3	2.02		0.501	0.004		42.2		0.026
14/9/81	1 (M)	0.38		0.506					
	2	0.41	457	0.528	0.002	0.004	42.4	3627	0.022
	3	1.34		0.501	0.006		43.5		0.024
15/10/81	1 (M)	0.08		0.506					
	2	2.14	384	0.528	0.011	0.046	44.6	4011	0.021
	3	15.40		0.501	0.080		58.9		0.029
11/12/81	1 (M)	0.02		0.506					
	2	0.21	54	0.528	0.007	0.030	44.8	4065	0.021
	3	1.41		0.501	0.052		60.4		0.030
1/7.82	1 (M)	1.01		0.506					
	2	32.98	1300	0.528	0.048	0.070	77.8	5365	0.027
	3	59.31		0.501	0.091		119.7		0.045
18/8/82	1 (M)	0.98		0.506					
	2	31.10	434	0.528	0.136	0.143	108.9	5799	0.036
	3	32.52		0.501	0.150		152.2		0.052
22/10/82	1 (M)	0.53		0.506					
	2	23.21	528	0.528	0.083	0.059	132.1	6327	0.040
	3	30.26		0.501	0.114		182.4		0.058

NOTES

Plot 1 was mulched (M); plots 2 and 3 were bare fallow.

Ac = Accumulative soil loss; Rc = accumulative erosivity factor; Kc = accumulative erodibility.

- Date not available.

the nomogram-estimated K values are also shown. The data in Table 7 show the parameters used to estimate K using the nomogram. The comparison between the measured and estimated K values shows that the nomogram-estimated values can be acceptable approximations during the first year. For Heipang, this is also the case for the following years. But for Ikom and Onne the difference between the measured and the estimated K increased with time.

The data support the need for an appropriate modification of this nomogram for use in tropical soils. Preliminary results from rainfall simulation tests which are not considered here indicate that the structural stability index is an important controlling factor. Erodibility is a function of both detachability and transportability. The collapse of structural aggregates associated with surface sealing directly influences both the detachability and the transportability

TABLE 5 Measured K values for field plots at Heipang

	Plot	Soil loss (A) (t ha ⁻¹)	Erosivity (R)	Slope-length factor (LS)	Measured erodibility (K):		Cumulative parameters:		
					Actual	Mean	Ac	Rc	Kc
24/7/80	1 (M)	0.05		0.251			-	-	-
	2	2.04	184	0.248	0.045	0.045	-	-	-
	3	1.83		0.223	0.045		-	-	-
22/9/80	1 (M)	0.07		0.251					
	2	2.81	82	0.248	0.124	0.117	4.85	276	0.071
	3	2.26		0.223	0.111		4.09		0.066
28/10/80	1 (M)	0.06		0.251					
	2	0.77	58	0.248	0.053	0.057	5.62	334	0.068
	3	0.81		0.223	0.062		4.90		0.066
13/7/80	1 (M)	0.08		0.251					
	2	3.95	387	0.248	0.041	0.042	9.57	721	0.054
	3	3.82		0.223	0.044		8.72		0.054
16/9/81	1 (M)	0.17		0.251					
	2	2.24	340	0.248	0.027	0.044	11.81	1061	0.045
	3	4.65		0.223	0.061		13.37		0.057
21/10/81	1 (M)	0.02		0.251					
	2	0.57	53	0.248	0.043	0.060	12.38	1114	0.045
	3	0.93		0.223	0.078		14.30		0.058
2/7/82	1 (M)	0.14		0.251					
	2	5.15	259	0.248	0.080	0.095	17.53	1373	0.051
	3	6.44		0.223	0.111		20.74		0.068
17/8/82	1 (M)	0.08		0.251					
	2	1.54	209	0.248	0.030	0.038	19.07	1582	0.049
	3	2.21		0.223	0.047		22.95		0.065
21/10/82	1 (M)	0.26		0.251					
	2	5.05	100	0.248	0.204	0.262	24.12	1682	0.058
	3	7.13		0.223	0.321		30.08		0.080

NOTES

See under Table 4.

components of rill-interrill erosion. The loss of structural stability under the impact of raindrops result in smaller and more easily transportable soil particles. The surface sealing, by reducing infiltration and increasing the amount of runoff water, increases the transportability of detached particles.

Mulch factor (M)

The mulch factor computed represents the C x P factors of the USLE and is an expression of the protection against erosion provided by the mulch layer. The following values of the mulch factor (M) may be derived from the data in Tables 4-6

Ikom: 0.026
Heipang: 0.034
Onne: 0.010

These values are extremely low and emphasize the excellent protection against rainfall erosion provided by mulch.

CONCLUSIONS

The directly measured erodibility factors (K) of three Nigerian soils indicate relatively low values of 0.02-0.04. These erodibility values are similar to those reported for some other

TABLE 6 Measured K values for field runoff plots at Onne

	Plot	Soil loss (A) (t ha ⁻¹)	Erosivity (R)	Slope-length factor (LS)	Measured erodibility (K):		Cumulative parameters		
					Actual	Mean	Ac	Rc	Kc
19/3/81	1 (M)	0.68	548	0.540			-	-	-
	2	1.51			0.005		-	-	-
	3	0.90			0.003	0.005	-	-	-
	4	1.75			0.006		-	-	-
12/6/81	1 (M)	0.76	532	0.540					
	2	40.79			0.142		42.3	1080	0.073
	3	40.79			0.142	0.145	41.69		0.071
	4	43.16			0.150		44.91		0.077
17/7/81	1 (M)	0.28	657	0.540					
	2	8.24			0.023		50.58	1737	0.054
	3	5.42			0.015	0.051	47.11		0.050
	4	4.47			0.013		49.38		0.053
8/9/81	1 (M)	0.19	323	0.540					
	2	7.82			0.045		58.4	2060	0.052
	3	12.70			0.073	0.051	59.81		0.054
	4	5.85			0.034		55.23		0.050
14/10/81	1 (M)	0.23	292	0.540					
	2	4.25			0.027		62.65	2351	0.049
	3	4.36			0.028	0.025	64.17		0.051
	4	3.20			0.020		58.43		0.046
10/21/81	1 (M)	0.04	128	0.540					
	2	4.10			0.059		66.75	2479	0.049
	3	5.24			0.076	0.073	69.41		0.052
	4	5.72			0.083		64.15		0.048
30/6/82	1 (M)	0.08	1596	0.540					
	2	129.34			0.150		196.09	4075	0.089
	3	134.62			0.156	0.155	204.03		0.093
	4	137.80			0.160		201.95		0.092
19/8/82	1 (M)	0.12	162	0.540					
	2	27.91			0.318		224.00	4237	0.098
	3	23.42			0.267	0.303	227.46		0.099
	4	28.53			0.325		230.48		0.101
23/10/82	1 (M)	0.22	641	0.540					
	2	43.28			0.125		267.28	2878	0.101
	3	28.69			0.083	0.097	256.15		0.097
	4	28.60			0.083		259.08		0.098

NOTES

See under Table 4

Plot 4 also bare fallow

soils of this region. (Lal, 1976; Roose, 1977). The nomogram-estimated values of soil erodibility differ considerably from those measured directly and there is therefore a need for appropriate

TABLE 7 Summary data used in the Wischmeier nomogram for estimating the K factor

	Silt + very fine sand (%)	Sand (%)	Organic matter (%)	Structure class	Perme- ability class	K nomogram
Ikom	10.7	4.9	6.1	2	1	0.01
Heipang	22.6	63.2	0.9	1	3	0.06
Onne	8.9	80.9	2.3	1	1	0.03

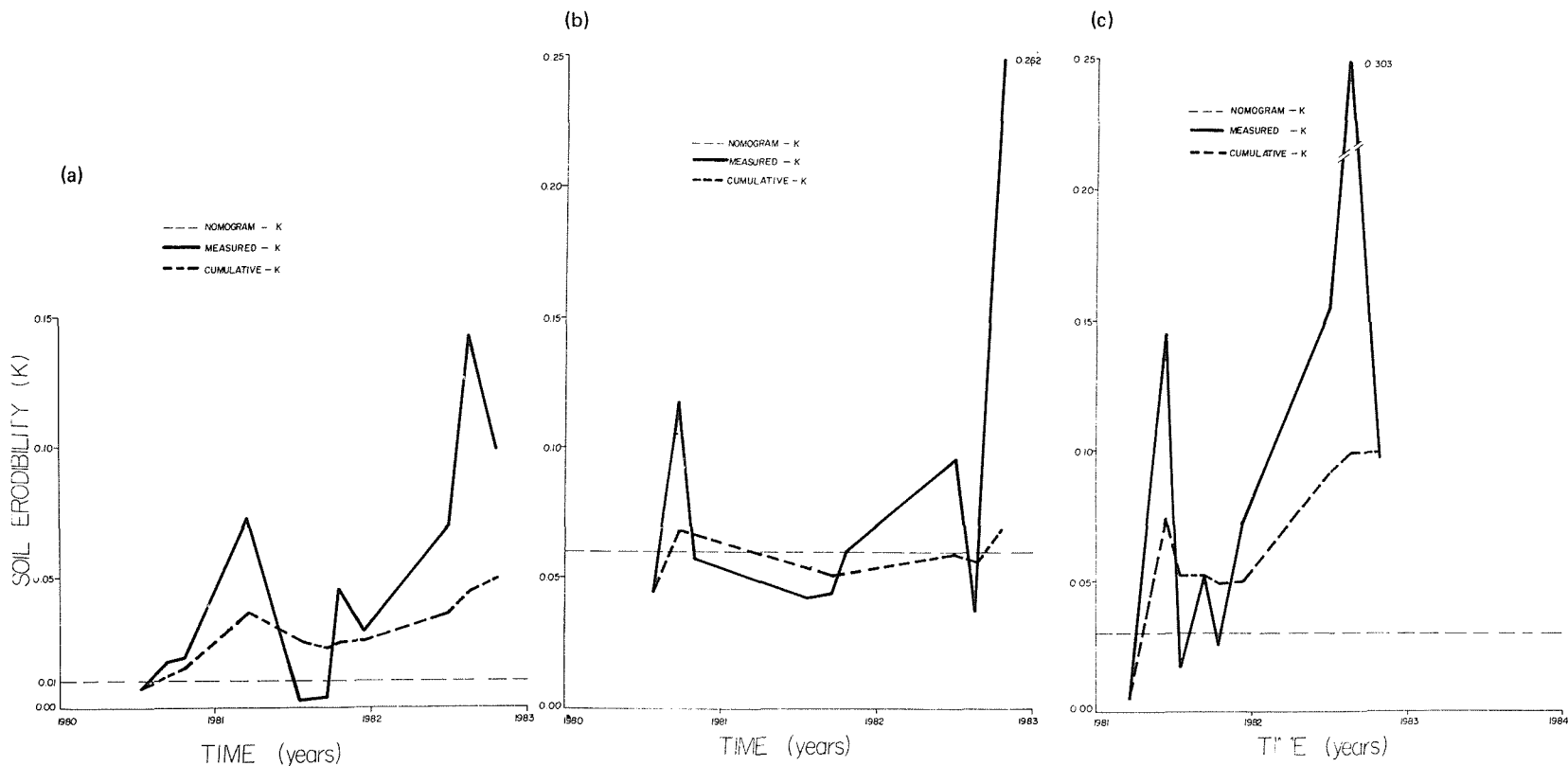


FIG.4 Comparison of measured and estimated erodibility for (a) a rhodustalf at Ikom; (b) an oxic paleustalf at Heipang, near Jos, and (c) a paleudult at Onne.

modifications to the nomogram if it is to be used for tropical soils. Factors which should be investigated include the structural stability index, surface sealing, and perhaps the concentration of Fe and Al oxides. Modification of the nomogram to include these factors will be attempted after additional laboratory data have been obtained using a rainfall simulator.

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