

## **Erosion characteristics of selected Southwestern Nigerian soils in relation to soil physicochemical properties, overland flow and chemical conditioning**

**D.J. OYEDELE and P.O. AINA**

*Soil Science Department  
Obafemi Awolowo University,  
Ile-Ife.*

### **Abstract**

Erosion was evaluated by the laboratory rainfall simulator for 5 widely distributed agricultural soils from Southwestern Nigeria in relation to soil physicochemical properties and effects of overland flow (at equivalent rates of 33 and 66 cm/hr) and chemical conditioning with ethylene glycol. Rainfall intensities of 12.5, 15.7, and 24.1 cm/hr were used on soil micro-plots tilted at 5% and 9% slopes. Erodibility of the soils varied with indices ranging from 0.017 to 0.157, and was related to soil contents of organic matter, sesquioxides and 2.250  $\mu$ m diameter particle fraction. Overland flow constituted a significant causative factor, causing as much as 33% erosion compared to rainfall erosion on some soils. The results ascertained the severity of erosion in the study area and also the possible use of ethylene glycol in erosion control without adverse effects on maize crop establishment.

### **Introduction**

Soil erosion by water involves the detachment of soil particles mostly by raindrop impacts and subsequent transportation of the detached particles by splash and rain-imparted overland flow. Both phases determine a soil's potential to erode with the relative contribution of each phase to soil erodibility depending on soil physical and chemical properties, and interaction between rainfall and overland flow (Mutchler and Hansen, 1970; Yariv 1976; Moss et al, 1979; Singer and Walker, 1983).

Soil erosion generally results in extensive land degradation through the physical removal of soil, fertility depletion, and reduction in land productivity. The extent of erosion in Nigeria as a whole is not known due to paucity of basic research information on the erodibility and its relationship to erosion causative factors and properties of the wide range of diverse soils. Also scarce is the information on effective methods for controlling erosion under the different ecologies. However, occurrence of spectacular gullies (Grove 1951; Ofomata, 1964) and the high rates of erosion reported from few scattered studies (Kowal, 1970; Lal 1976; Aina et al, 1980; Vaneland et al, 1984, 1985) coupled with the rather low soil loss tolerance of the soils (Lal, 1983) indicate that water erosion can be very severe in most parts of Nigeria. There is a need to investigate the quantitative relationships between erodibility and soil properties on one hand and erosion control methods on the other hand for the major Nigerian soils in order to enhance the development of appropriate soil and water conservation programmes. Considering the diversity of soils and ecologies, direct field-plot measurements of soil erodibility will involve prohibitively high cost and long duration. Use of laboratory-based rainfall simulator therefore is desirable for expedient acquisition of data relating to relative erodibility of soils, erosion processes and the effectiveness of some control measures.

The objective of this study was to evaluate soil erosion potentials for some widely occurring soils of Southwestern Nigeria in relation to their physical and chemical properties, the contribution of overland flow to erosion process and the effect of chemical conditioning.

### Materials and Methods

Surface soil samples (0-15cm) of five widely occurring soils were obtained from locations (Fig. 1) under bush regrowth in Southwestern Nigeria. Selected properties and the classification of the soils are given the Table 1. The samples were air-dried, sieved through 10-mm sieve and packed in wooden boxes (micro-plots) that were 122 cm long x 35cm x 15cm high and equipped with perforated base and facilities for the measurement of run-off, soil splash and erosional soil wash. Each micro-plot, inclined at 5% and 9% slope, was subjected to simulated rainfall, overland flow or both for 30 minutes. Overland flow was delivered through a constant head storage and a series of baffles to dampen turbulence.

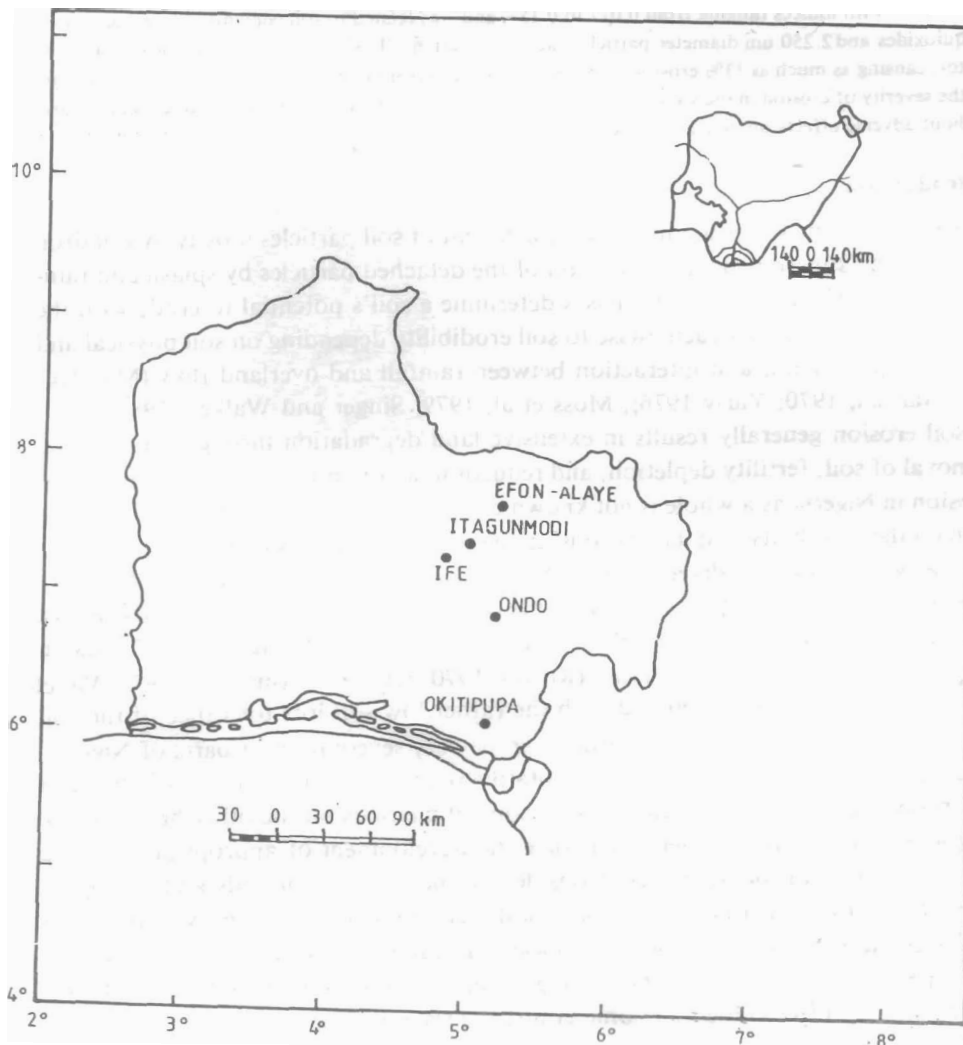


TABLE 1: CLASSIFICATION AND SELECTED PROPERTIES OF THE SOILS USED

| Soil       | Location       | Classifi-<br>cation | Particle Size Dist |           |      | Exchangeable Bases |     |                   |      |      |      |      |        | Fe <sub>2</sub> O <sub>3</sub> |         | Al <sub>2</sub> O <sub>3</sub> |         |                 |
|------------|----------------|---------------------|--------------------|-----------|------|--------------------|-----|-------------------|------|------|------|------|--------|--------------------------------|---------|--------------------------------|---------|-----------------|
|            |                |                     | Sand               | Silt<br>% | Clay | H <sub>2</sub> O   | KCl | CaCl <sub>2</sub> | Ca   | Mg   | K    | Na   | C.F.C. | Organic<br>Matter              | Oxalate | Dithio-<br>nite<br>%           | Oxalate | Dithio-<br>nite |
|            |                |                     |                    |           |      |                    |     |                   |      |      |      |      |        |                                |         |                                |         |                 |
| Iwo        | Ile-Ife        | Alisol              | 73.6               | 12.1      | 14.3 | 6.9                | 6.0 | 6.4               | 2.20 | 0.33 | 0.32 | 0.13 | 3.18   | 1.89                           | 0.06    | 0.85                           | 0.05    | 0.18            |
| Itagunmodi | Ilesha         | Alfisol             | 54.3               | 22.4      | 23.3 | 6.4                | 5.8 | 6.1               | 4.40 | 4.17 | 0.87 | 0.23 | 10.07  | 4.33                           | 0.12    | 2.34                           | 0.12    | 0.14            |
| Alagba     | Okitipupa      | Ultisol             | 80.7               | 20        | 12.3 | 5.3                | 4.8 | 5.1               | 0.75 | 0.92 | 0.18 | 0.04 | 3.59   | 2.01                           | 0.10    | 1.29                           | 0.09    | 0.21            |
| Ondo       | Ondo           | Alfisol             | 62.5               | 20.0      | 17.3 | 6.7                | 6.1 | 6.5               | 2.75 | 0.42 | 0.54 | 0.26 | 4.07   | 3.35                           | 0.06    | 1.19                           | 0.06    | 0.12            |
| Okemesi    | Efon-<br>Alaye | Inceptisol          | 75.1               | 7.3       | 17.3 | 6.0                | 5.3 | 5.9               | 4.20 | 0.51 | 0.45 | 0.20 | 5.66   | 3.00                           | 0.12    | 1.54                           | 0.09    | 0.12            |

The experiments which were carried out in a factorial design with three replicates had treatments consisting of rainfall at 0, 12.5, 15.7 and 24.1 cm/hr intensities, overland flow at the rates of 0.33 and 66cm/hr and chemical treatment with ethylene glycol applied to soil surface at 0 and 0.6 litre/m<sup>2</sup>. All run-off water and transported soil were collected at each rainfall or overland flow event. Run-off samples were filtered to determine the sediment loss. Maize was planted in treated (with conditioner) and untreated microplots which then received 12.5cm/hr rainfall for 30 minutes and observations were made on seedling emergence rate, growth and dry matter yield at four weeks after emergence.

All soils were analysed for organic carbon by the Walkley-Black method (Allison, 1965); pH in water, KCl and CaCl<sub>2</sub>; particle size distribution by the hydrometer method (Bouyoucos, 1961); exchangeable bases (Ca<sup>2+</sup>, Na<sup>+</sup> and K<sup>+</sup>) by the standard ammonium acetate extraction method; free Fe and Al Oxides according to the procedure given by Mehra and Jackson (1960) using a dithionite-citrate-NaHCO<sub>3</sub> system and amorphous Fe and Al were extracted from soils according to Schwertmann (1959). Structural properties were determined by the water coherence test (Greenland et al., 1975) and water drop technique (Bruce-Okine and Lal, 1975).

On the basis of the data obtained soil erodibility, K was computed as:

$$K = A/(R LS)$$

where A is the observed total soil loss in ton/ha, R is rainfall erosivity index and LS which is the topographic factor was calculated from the following equation: (Rubio-Montoya and Brown, 1984):

$LS = (\lambda/22.14)^m (65.41 \sin^2 \theta + 4.65 \sin \theta + 0.65)$  where  $\lambda$  is the length of the microplot in meters,  $\theta$  is the slope angle, m is a function of slope with values of 0.4 at 5% and 0.5 at 9% slopes.

Soil erodibility ( $K_m$ ) was also estimated using the monograph of Wischmeier et al, (1971). Comparisons were made between these erodibility values and those predicted from soil physico-chemical properties.

## Results and Discussion

### Soil erodibility

There were significant differences in erosion among soils and among the different treatments. As indicated in Fig. 2, soils demonstrated an approximately ninefold difference in soil loss from 1.2kg/m<sup>2</sup> for Okemesi soil to 10.9 kg/m<sup>2</sup> for the Alagba soil, averaged over slope and rainfall intensities. Significant differences were also observed in the splash erosion measurement, ranging from 0.15kg/m<sup>2</sup> to 0.62 kg/m<sup>2</sup> on the respective soils. Soil splash as measured here was only a minor contribution (<6%) to total soil loss. Run-off showed no consistent relationship with soil loss. However, low run-off was generally associated with low soil loss on the more permeable soils (Okemesi and Itagunmodi).

Total potential erosion is considered high for three (Iwo, Ondo and Alagba Soils) of the five soils as evident from the measured relative erodibility (K) values (Table 2) and considering the high erodibility established in an earlier field study by Wilkinson, 1975 for Iwo soil. Erodibility values ranged from 0.02 for Okemesi soil to 0.16 for Alagba soil with the overall potential of the soils to erode in the following decreasing order: Alagba > Ondo > Iwo > Itagunmodi > Okemesi. Erodibility has been reported

to depend on many soil properties including texture, organic matter, permeability, soil structure (Wischmeier and Mannering, 1969; Bryan, 1968), concentration of oxides of Fe and Al, mineralogy and surface charge characteristics which have an important effect on detachability and dispersion. The correlation co-efficient of K with soil properties (Table 3) was significantly negative for percent clay, organic carbon and concentration of Fe and Al but positively with 2-250um particle size fraction. The analysis of eroded sediments revealed that a high proportion of eroded soil was

**TABLE 2: THE SOIL ERODIBILITY (K) VALUES**

| Soil       | Measured, K | Nomograph, $K_m$ |
|------------|-------------|------------------|
| Iwo        | 0.11        | 0.26             |
| Itagunmodi | 0.03        | 0.21             |
| Alagba     | 0.16        | 0.19             |
| Ondo       | 0.15        | 0.23             |
| Okemesi    | 0.02        | 0.04             |

**TABLE 3: CORRELATION COEFFICIENT (r) OF MEASURED SOIL ERODIBILITY WITH SOIL PROPERTIES.**

| Soil Properties                       | r        |
|---------------------------------------|----------|
| Soil fine particle fraction (2-250 m) | 0.74.*   |
| C.E.C.                                | -0.71*   |
| % Clay                                | -0.69*   |
| % extractable Fe + Al oxides          | -0.66*   |
| % Coarse sand                         | 0.52n.s. |
| % Organic matter                      | -0.61*   |
| Bulk density                          | 0.40n.s. |
| 9 pH                                  | 0.19n.s. |

\*  $pH = pH_{H_2O} - pH_{KCl}$

\*\* Value significant at 1% level of probability

\* Value significant at 5% level of probability

n.s. Value not significant at 5% level of probability

made of 2-250 um size particles.

In this study, slaking of aggregates and surface crust or seal development was quite evident on most of the soils at the conclusion of the rainfall or overland flow event with the exception of Okemesi and Itagunmodi soils. These latter soils were characterized by high permeability and low erosion, due to either the coarse-textural nature (Okemesi) or stable surface structure (Itagunmodi). The other soils which were more susceptible to erosion had low contents of organic matter, clay and Fe and Al and high 2 - 250 um particle fraction.

The following step-wise regression equation of K with routinely determined soil parameters explained 89% of variation in K:

$$K = 0.0032 + 1.52T - 2.00C + 0.69E + 6.34M$$

where T is the fraction of 2-250 $\mu$ m particle, C is the proportion of clay, E is the fractional concentration of Fe and Al oxides and M is the organic matter fraction. The comparison of K with Wischmeier et al's (1971) monograph-estimated erodibility values ( $K_m$ ) showed substantial differences with no consistent trends. K values were lower than  $K_m$  values on all soils. The disparity however appeared to be greater among the finer-textural soils.

#### *Overland flow*

Soil losses in events with overland flow alone varied greatly among soils and treatments but were generally less than those for events with rainfall alone (Table 4). The results indicate greater effectiveness of rain-imparted run-off in detaching and transporting soil in erosion process than unimpacted run-off. Similar observations have been made in a number of studies (Singer and Blackard, 1978). However, observations on the Iwo soil are noteworthy and point to the fact that overland flow alone can be a significant erosive agency on weakly structured soils. On this soil, overland flow, averaged over application rates, accounted for as much as 33% of total soil loss within the range of experimental conditions used. On other soils, while the lower overland flow rate (33 cm/hr) was not effective in causing erosion on the Itagunmodi and Okemesi soils, it resulted in about 0.05 kg/m<sup>2</sup> soil loss on Iwo soil. Itagunmodi soil became slightly susceptible at the higher rate of 66 cm/hr at which minor rilling was observed on the soils.

Fig. 3 shows the evidence of the interactive nature of rainfall and overland flow. Rainfall with added overland flow was much more effective in erosion compared to the same amount of water added as rainfall or overland flow alone. This result is in agreement with earlier research (Ellison, 1945; Osborn, 1954) which had suggested strong interaction between rainfall and overland flow acting together to increase erosion. Although soil splash was reduced with addition of overland flow apparently due to increased surface flow depth, the interaction between rainfall and overland flow increased the erosive power of run-off and volume of water discharged due to the development of surface seal by raindrop impacts.

**TABLE 4: INFLUENCE OF RAINFALL, OVERLAND FLOW AND THEIR INTERACTION ON SOIL LOSS**  
**TABLE 4: I TER (kg/m<sup>2</sup>/cm WATER APPLIED)**

| Soil       | Overland flow rate (cm/hr) |       |       |       |       |       |       |       |       |
|------------|----------------------------|-------|-------|-------|-------|-------|-------|-------|-------|
|            | 0                          |       |       | 33    |       |       | 66    |       |       |
|            | Rainfall intensity (cm/hr) |       |       |       |       |       |       |       |       |
|            | 0                          | 12.5  | 15.7  | 0     | 12.5  | 15.7  | 0     | 12.5  | 15.7  |
| Iwo        | 0                          | 0.024 | 0.173 | 0.002 | 0.042 | 0.064 | 0.087 | 0.095 | 0.157 |
| Itagunmodi | 0                          | 0.019 | 0.073 | 0     | 0.018 | 0.050 | 0.031 | 0.051 | 0.062 |
| Ondo       | 0                          | 0.038 | 0.110 | 0.002 | 0.016 | 0.048 | 0.021 | 0.051 | 0.078 |
| Okemesi    | 0                          | 0.002 | 0.005 | 0     | 0.001 | 0.001 | 0     | 0.001 | 0.002 |

SOIL LOSS  
% RUN OFF

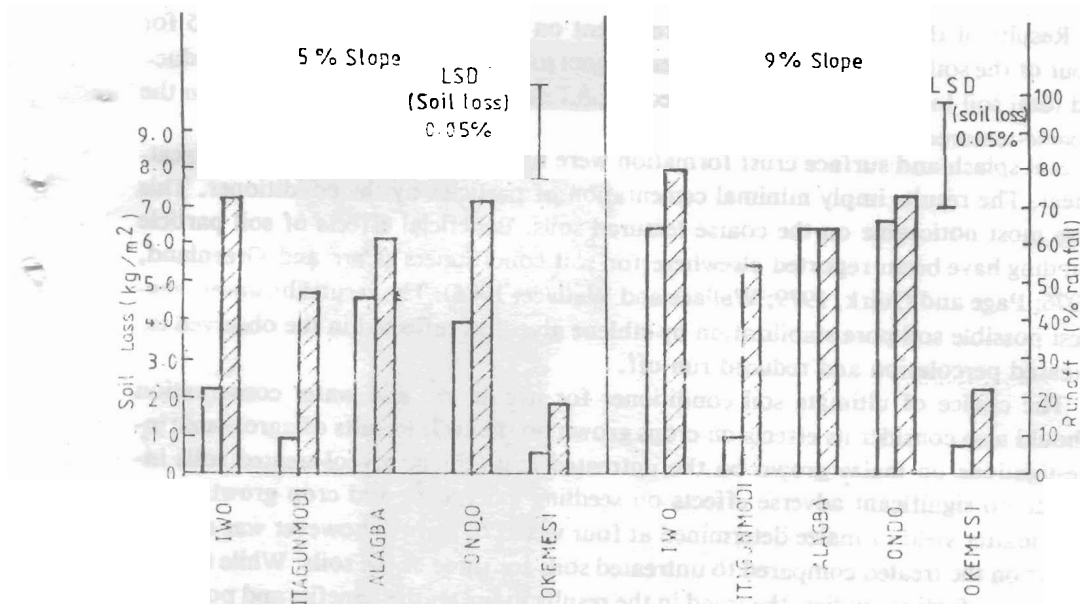


Fig. 2

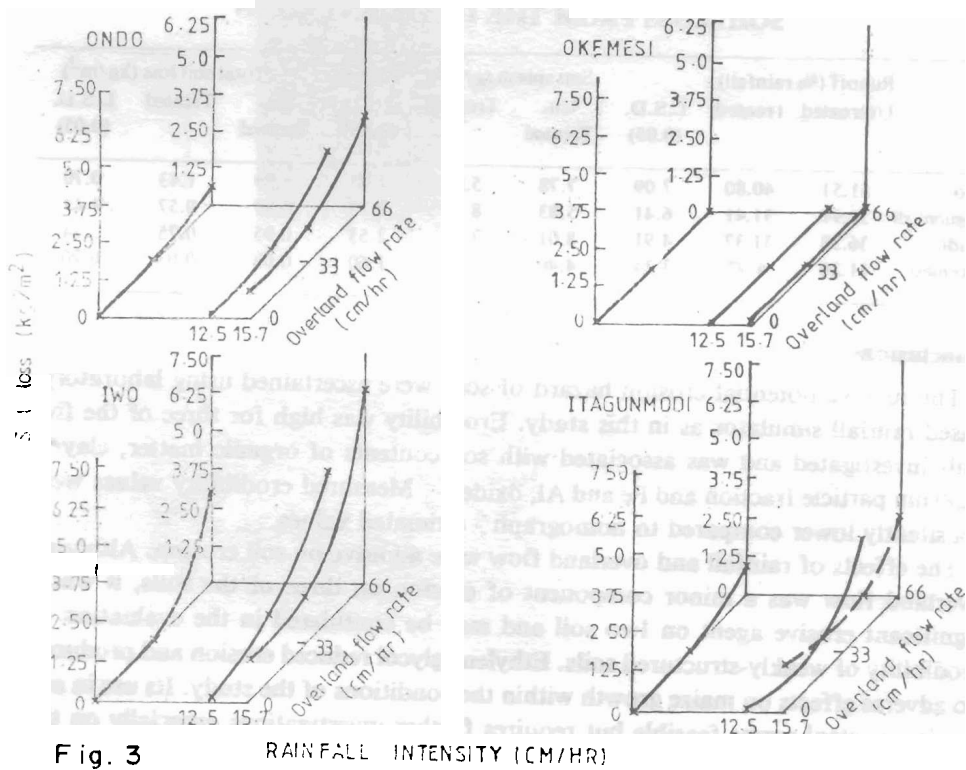


Fig. 3

RAIN FALL INTENSITY (CM/HR)

### *Soil Chemical Conditioning.*

Results of the effect of chemical treatment on erosion are shown in Table 5 for four of the soils. Application of ethylene glycol to soil at the rate of  $0.6 \text{ l/m}^2$  reduced total soil loss and run-off; the effectiveness however, appeared to be less on the coarse-textured soils.

Soil splash and surface crust formation were not affected by ethylene glycol treatment. The results imply minimal cementation of particles by the conditioner. This was most noticeable on the coarse textured soils. Beneficial effects of soil particle binding have been reported elsewhere for soil conditioners (Carr and Greenland, 1976; Page and Quirk, 1979; Wallace and Wallace, 1986). The results however suggest possible soil pore stabilization by ethylene glycol as reflected in the observed increased percolation and reduced run-off.

The choice of ultimate soil conditioner for use in soil and water conservation should also consider its effects on crops grown on the soil. Results of agronomic investigations on maize grown on the untreated and ethylene glycol-treated soils indicate no significant adverse effects on seedling emergence and crop growth rate. Dry matter yield of maize determined at four weeks of growth however was slightly lower on the treated compared to untreated soils for three of the soils. While there is a need for further studies, the trend in the results indicates the benefits and possibility of chemical conditioning of the soils for soil and water conservation.

**TABLE 5: EFFECTS OF ETHYLENE GLYCOL ON RUNOFF, SPLASH AND SOIL LOSS FROM THE DIFFERENT SOILS**

|            | Runoff (% rainfall) |         |                  | Soil splash ( $\mu/\text{m}^2$ ) |         |                  | Total soil loss ( $\text{kg}/\text{m}^2$ ) |         |                  |
|------------|---------------------|---------|------------------|----------------------------------|---------|------------------|--------------------------------------------|---------|------------------|
|            | Untreated           | Treated | L.S.D.<br>(0.05) | Un-<br>Treated                   | Treated | L.S.D.<br>(0.05) | Un-<br>Treated                             | Treated | L.S.D.<br>(0.05) |
| Iwo        | 51.51               | 40.80   | 7.09             | 7.78                             | 5.81    | 2.75             | 1.89                                       | 1.43    | 0.70             |
| Itagunmodi | 34.91               | 31.41   | 6.41             | 5.83                             | 8.78    | 2.75             | 0.87                                       | 0.57    | 0.25             |
| Ondo       | 36.38               | 31.37   | 4.91             | 8.01                             | 7.45    | 2.53             | 0.95                                       | 0.75    | 0.14             |
| Okemesi    | 11.20               | 4.97    | 3.24             | 4.40                             | 4.87    | 1.60             | 0.03                                       | 0.03    | 0.20             |

### **Conclusions**

The relative potential erosion hazard of soils were ascertained using laboratory-based rainfall simulator as in this study. Erodibility was high for three of the five soils investigated and was associated with soil contents of organic matter, clay, 2-250  $\mu\text{m}$  particle fraction and Fe and Al, oxides. Measured erodibility values were consistently lower compared to nomograph - estimated values.

The effects of rainfall and overland flow were additive on soil erosion. Although overland flow was a minor component of erosion on three of the soils, it was a significant erosive agent on Iwo soil and may be considered in the evaluation of erodibility of weakly-structured soils. Ethylene glycol reduced erosion and produced no adverse effects on maize growth within the conditions of the study. Its use in soil erosion control seems feasible but requires further investigations especially on the rate of application and effects on crops.

## References

- Aina, P.O., Lal, R., and Taylor, G.S. (1980). Relative susceptibility of some Nigerian soils to erosion. *Nig. J. Soil Sci. 1*: 1-19.
- Allison, L.E. (1965). Organic Carbon analysis. In Black C.A., D. Evans, J.I. White, L.E. Esminger and F.E. Clark (eds). *Methods of Soil analysis. Part II: 1367 - 1378. American Soc. of Agron. Publ. No. 10.*
- Bouyoucos, G.J. (1961). Hydrometer method improved for making particle size analysis of soils. *Agron. J. 27*: 738-741.
- Bruce-Okine, E., and Lal, R. (1975). Soil erodibility as determined by raindrop technique. *Soil Sci. 11*(2): 149-157.
- Bryan R.B. (1969). The development, use and efficiency of indices of soil erodibility. *Geoderma 2*:5-5 - 26.
- Carr, C.E. and Greenland, D.J. (1976). Potential application of PVAC and PVA on structural improvement of sodic soils. *Soils and Fertilizers. (Abstr)*: 537.
- Ellison, W.D. (1945). Some effects of raindrop and surface flow on soil erosion and infiltration. *Trans. Am. Geophys. Union 26*:415-429.
- Greenland, D.J., Rimmer, D. and Payne, D. (1976). Determination of the structural stability class of English and Welsh soils, using a water coherence test. *J. Soil Sci. 26*(3): 294-300.
- Grove, A.T. (1951). Soil erosion and population problems in S.E. Nigeria. *Geog Journ. (XVII) 3*: 291-306.
- Kowal, J. (1970). The hydrology of a small catchment basin of Samaru, Nigeria, III. Assessment of soil erosion under varied land management and vegetation cover. *Nig. Agric. J. 7*: 163-173.
- Lal, R. (1976). Soil erosion problems on Alfisol in Western Nigeria and their control. *IITA Monogram No. 1* 280 pp.
- Lal, R. (1983). Soil erosion in the humid tropics with particular reference to agricultural land development and soil management. *IAHS Publ. No. 140*: 221-239.
- Mehra, O.P., and Jackson, M.L. 1960. Iron oxide removal from soils and clays by a dithionite citrate system buffered with sodium bicarbonate. *Clays Clay Miner. 7*:317-327.
- Moss, A.,J. Walker, P.H. and Hutka, J. (1979). Raindrop simulated transportation in shallow water flows: an experimental study. *Sediment Geol. 22*:165-184.
- Mutchler, C.K. and Hansen L.M. (1970). *Splash of water drop at terminal velocity. Science (N.Y.) 167*: 1311 — 1312.
- Ofomata, G.E.K. (1964). Soil erosion in Enugu region of Nigeria. *Afr. Soils 9* (2): 259—348.
- Osborn, B. (1954). Soil splash by raindrop impact on bare soils. *J. Soil and Water Conserv. 9*: 33—38.
- Page, E.R. and Quirk, M.J. (1970). A comparison of the effectiveness of organic polymers as anti-crusting agents. *J. Soil Science. 138*(5): 365—373.
- Schwertmann, U., 1959. The differentiation of iron oxide in soils by a photochemical extraction with acid ammonium oxalate. *Z. Pflanzenernahr. Dung. Bodenkunde 105*: 194—202.

- Singer, M.J. and Blackard, J. (1981). Effects of mulching on sediment in run-off from simulated rainfall. *Soil Sci. Soc. Am. J.* 42: 481—485.
- Singer, M.J. and Walker, P.H. (1983). Rainfall-runoff in soil erosion with simulated rainfall, overland, flow and cover. *Aust. J. Soil Res.* 21: 109-122.
- Vanelslande, A., Rouseau, A.P., Lal, R., Gabriels, D. and Ghuman, B.S. (1984). Testing the applicability of soil erodibility nomograph for some tropical soils *IHIAHS Publ.* 144: 463—473.
- Vanelslande, A., Lal, R. and Gabriels, D. (1985). Erodibility of some Nigerian soils. *Proc. Inter. Symp. Soil erosion, debris flow and disaster prevention, Tsukukuber Japan* 51—56.
- Wilkinson, G.E. (1975). Rainfall characteristics and soil erosion in the rainforest area of Western Nigeria. *Expl. Agric.* 11:247—255.
- Yariv, S. (1976). Comments on the mechanisms of soil detachment by rainfall. *Geoderma.* 15:393—399.
- Rubio-Montova, D. and Brown, K.W. 1984. Erodibility of strip-mine spoils. *Soil Science.* 138(5): 365—373.