*Hydrological Sciences – Journal – des Sciences Hydrologiques*, 30, 2, 6/1985

# Soil erosion and sediment transport research in tropical Africa*

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ABSTRACT This paper reviews the magnitude of soil erosion in tropical Africa and relates it to erodibility, erosivity and landform in different ecological regions There are few direct measurements of erosivity and erodibility in tropical Africa and the relevance of using the Universal Soil Loss Equation in estimating these parameters is reviewed. Soil erodibility is not a fixed parameter and changes with time. Although localized rates of soil erosion can be high, the erosion rates derived from sediment loads in rivers are often low. Most of the available data on sediment loads of African rivers are 10-20 years old, and little research information is available on the delivery ratios associated with different catchments. Rapidly changing land useis one of the major factors responsible for accelerated soil erosion, and the effects of deforestation, grazing, fire, and of cultural practices are discussed. The economics of soil erosion is reviewed in terms of loss in productivity and siltation of reservoirs. Research and development needs are listed.

*Recherche sur l'érosion du sol et le transport des sédiments en Afrique tropicale*

RESUME Cet article passe en revue l'ampleur de l'érosion du sol en Afrique tropicale en relation avec l'érodibilité, l'érosivité et les formes de paysage dans différents sites écologiques. Il y a peu de mesures directes d'érosivité en Afrique tropicale et la pertinence de l'utilisation de l'Equation Universelle de Perte de Sol dans l'estimation de ces paramètres est analysée. L'érodibilité du sol n'est pas un paramètre fixé. Il change avec le temps. Bien que l'érosion d'un sol déterminé puisse être grande, le taux d'érosion évalués à partir des charges de sédiments dans les rivières sont souvent faibles. La plupart des données disponibles sur les charges de sédiments des rivières africaines datent de 10 à 20 ans, et peu d'informations sur la base de la recherche sont disponibles sur la proportion des apports des différents bassins hydrographiques. L'utilisation rapidement changeante du

*view paper presented at the International Symposium on ...llenges in African Hydrology and Water Resources, Harare, ...babwe, July 1984.*



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sol est un des facteurs majeurs responsable de l'érosion accélérée du sol, et les effets de déforestation, de pâturage, du feu et des pratiques culturales sont discutés. Les aspects économiques de l'érosion du sol sont passés en revue en terme de perte de productivité et d'accumulation de sédiments dans les réservoirs. Les besoins de la recherche et du développement sont énumérés.

## INTRODUCTION

Tropical Africa, the region lying within 23° north and south of the equator, has a history of over 50 years of research in soil erosion and sediment transport. The available literature indicates severe soil erosion hazards in different ecological regions. The alarming rates of soil degradation and desertification have been reported by many (Dregne, 1978, 1982). In the Sahel, severe flash flood and gully erosion are commonly observed during the monsoon. Talbot & Williams (1978) observed gullies 150 to 300 m long formed during one short rainy season in the Sahel zone of Niger. The Sahel also suffers from excess wind erosion during the dry season (Barth, 1978; Prospero *et al.*, 1981). In the savanna regions, severe erosion has been reported from Ghana by Adu (1972), and rates of 174-602 $m^3 km^{-2} year^{-1}$ and 1800 t $km^{-2} year^{-1}$ have been documented from Tanzania (Christiansson, 1981), and Lesotho (Chakela, 1981) respectively. Soil erosion also continues unabated in the semiarid regions of tropical Africa. Savat & Poesen (1977) observed in Central Africa that the sandy dome-shaped hills south of Kinshasa were denuded by splash and discontinuous runoff. In Nigeria, Oyebande (1981) reported a maximum annual suspended sediment yield of 483 t $km^{-2} year^{-1}$. Balek (1977) reported a high sediment load of 1804 t $km^{-2} year^{-1}$ from Malawi. Soil erosion is even more severe in the highlands (Rapp *et al.*, 1972). Virgo & Munro (1978) observed that about 6000 $km^2$ of the Central Plateau region of Tigrai, Ethiopia, was affected by severe soil erosion.

The rate of natural erosion in the world is estimated to be 10-50 $m^3 km^{-2} year^{-1}$ with rates increasing to 100-500 $m^3 km^{-2} year^{-1}$ in the mountainous regions (Kadomura & Yamamoto, 1979). In contrast, Fournier (1962) estimated the potential denudation rate of the subhumid and semiarid regions of Africa to be 1430 $m^3 km^{-2} year^{-1}$. The potential denudation rate for Africa as a whole was estimated to be 510 $m^3 km^{-2} year^{-1}$, which was 9 times that for continental Europe and 10 times the overall rate for the world. There are no doubt areas within tropical Africa with little or slight soil erosion, but vast regions of some susceptible soils are prone to severe gully erosion, for example the southeastern region of Nigeria (Fig.1).

Some observations reported in the literature are based on qualitative and reconnaissance surveys and lack a strong data base. The lack of supporting technical data has often led to erroneous and conflicting estimates of the erosion hazard. For example, estimates of denudation rates made by Fournier (1962) and by Strakhov (1967) differ by several orders of magnitude. It is important, therefore, to improve the data base in order to produce reliable conclusions

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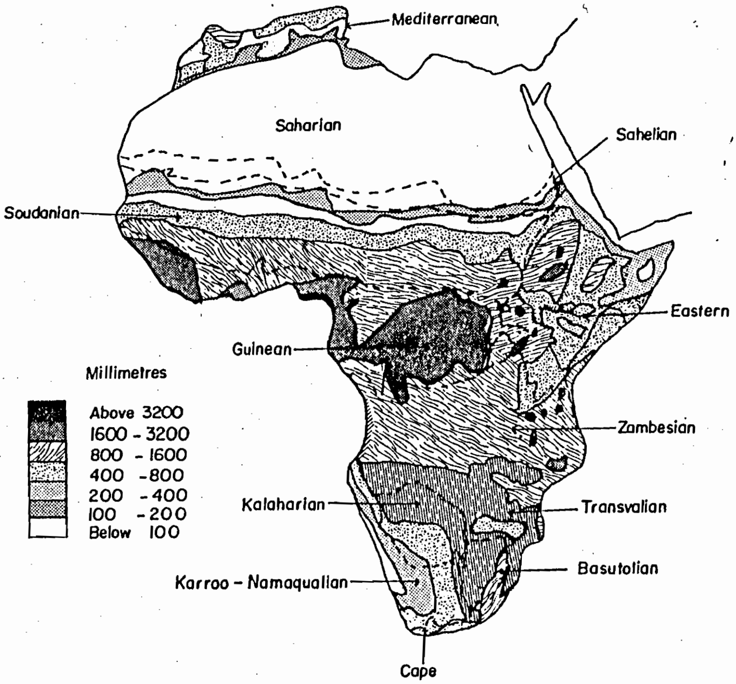


**Fig. 1** Ecological map of tropical Africa (adapted from De Vos, 1975).

## ECOLOGICAL FACTORS AND SOIL EROSION

Accelerated soil erosion is a symptom of ecological imbalance. It is a multi-faceted and complex process that is affected by a multitude of interacting environmental parameters (Vuillaume, 1982).

### *Rainfall*

The high erosivity of tropical rains is obviously an important factor responsible for widespread erosion. Maximum daily rainfall of 220-430 mm is often observed in many regions of tropical Africa (Balek, 1983). Jansson (1982) prepared a map of Africa depicting 1-h maximum rainfall with 2-year return period. Some Guinean, Soudanian and Zambesian ecological regions (Fig.1) lie within the zones that have a 1-h maximum rainfall intensity of 50-75 mm $h^{-1}$. Consequently, some of these regions have an annual runoff of 400-1000 mm (Jansson, 1982). In general, annual runoff increases with increasing annual rainfall (Balek, 1977).

Localized rainfall intensities exceeding 100 mm $h^{-1}$ sustained for 10-15 minutes are frequently observed (Wilkinson, 1975a; Kowal & Kassam, 1976; Lal, 1981b). High intensity rains are particularly damaging at times when the vegetation cover is poor (Wilkinson, 1975b; Stocking & Elwell, 1976). The high intensity of tropical rains is partly attributed to relatively large drop sizes. Observations made in the savanna (Kowal & Kassam, 1976) and forest regions of Nigeria (Aina *et al.*, 1977; Lal, 1981b) indicate that

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rains with median drop size in excess of 2.5 mm are common. Rains with an energy load of 100 J $m^{-2}mm^{-1}$ of rain are often received at a time when the protective vegetation cover is poor (Lal, 1981b). The energy load of rains in western Africa is generally more than that of the subtropical rains of Zimbabwe reported by Elwell & Stocking (1975). While characterizing the erosive effects of tropical rains in East Africa, Rose (1960) observed that the mass of soil detached per unit area was more closely related to the momentum than to the kinetic energy of a rainfall. Lal (1981b) has developed an empirical relation relating momentum and kinetic energy to rainfall amount and intensity.

*Soils*

Soils with low levels of organic matter content and those containing predominantly low-activity clays are susceptible to severe soil erosion. The predominant soils of tropical Africa are shown in Fig.2. Alfisols, the predominant soils of the subhumid and semiarid regions, are particularly susceptible to soil erosion. Ultisols, the soils of the humid Soudanian zone are also susceptible to erosion. Vertisols, soils of heavy texture and low permeability, are particularly susceptible to severe sheet and gully erosion.

Soil erodibility, defined as the erosion per annum per unit of the erosivity factor R, varies widely among soils derived from different parent materials (Table 1). Although quantitative measurements of erodibility have been made for only a few soils, the available data indicate a wide variation in the erodibility factor K, among soils. For example, Barber *et al*. (1979) observed that the erodibility of some soils of Kenya ranged from 0.03 to 0.49. Soil properties that result in low infiltration and in low soil-water storage increase susceptibility to erosion (Franzle, 1976). In the semiarid and dry lands, the presence of sodium on the exchange complex impairs infiltration and increases erosion risk (Stocking, 1976).

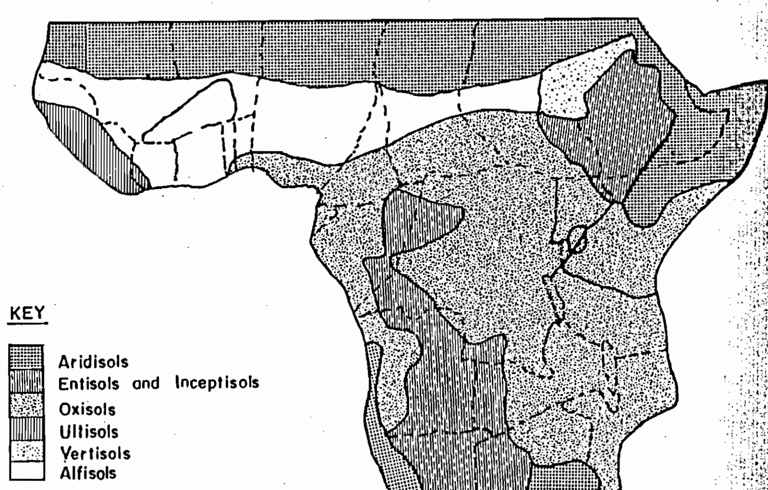


Fig. 2 Soil map of tropical Africa (adapted from Foth & Schaffer, 1980).

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**Table 1** Erodibility of some soils in tropical Africa

| Country | Region | Erodibility | Reference |
|---|---|---|---|
| Nigeria | Humid | 0.04 | Van Elslande *et al.* (1984) |
| Nigeria | Humid | 0.12-0.48 | Niger Techno Ltd (1975) |
| Nigeria | Subhumid | 0.06-0.36 | Lal (1976, 1981a, 1983) |
| Nigeria | Subhumid | 0.058 | Wilkinson (1975a, b) |
| Nigeria | Semiarid | 0.04 | Van Elslande *et al.* (1984) |
| Kenya | Subhumid | 0.19-0.30 | Dunne (1979) |
| Kenya | Subhumid | 0.03-0.49 | Barber *et al.* (1979) |
| Ivory Coast | Subhumid | 0.10 | Roose (1977) |
| Benin | Subhumid | 0.10 | Roose (1977) |
| Senegal | Semiarid | 0.25 | Charreau (1972) |
| Upper Volta | Semiarid | 0.25 | Roose (1977) |
| Tanzania | Semiarid | 0.12-0.16 | Ngatunga *et al.* (1984) |

Soil erodibility data reported in the literature require careful evaluation. Erodibility estimates based on the nomogram developed by Wischmeier *et al.* (1971) are not always reliable (Vanelslande *et al.*, 1984; Ngatunga *et al.*, 1984). Furthermore data obtained with laboratory-analysed indices and by simulated rainfall techniques (Platford, 1982) are an indication more of a soil's detachability (Bruce-Okine & Lal, 1975) than of its erodibility. Erodibility comprises both soil detachability and transportability and the latter can be monitored only if the experimental conditions permit the build-up of runoff velocity over sufficient length to include its effect on sediment detachment and transport. In addition, soil erodibility, as defined in the Universal Soil Loss Equation, is not independent of erosivity. In fact, erodibility decreases with increased rainfall erosivity. The available literature also indicates that the soil erodibility (factor K) is not constant, but changes with time and with management (Fig.3). Erodibility of tropical soils is significantly altered by changes in soil organic matter content, and the latter declines rapidly with cultivation. Soil erodibility also depends on plot size, i.e., erodibility increases with an increase in slope length (Lal, 1984b).

*Landforms*

Little is known regarding the effects of slope length and profile form on runoff and erosion. The erosion processes vary considerably with landform (Chakela, 1981). For example, sheet erosion and rain splash occur on uncultivated slopes, sheet and rill erosion are common on cultivated slopes and undulating and rolling dissected plains, and mass movement and gully erosion are severe on overgrazed slopes with stepped profiles. Lal (1976; 1983; 1984b) observed that the effect of slope length is less important than that of slope steepness and of slope form. It is in fact difficult to relate sediment transport to a measureable slope parameter. Soil loss from complex slopes is the least understood.

Regional and national maps of erosivity and potential erosion risks have been prepared by many workers (e.g. Roose, 1977;

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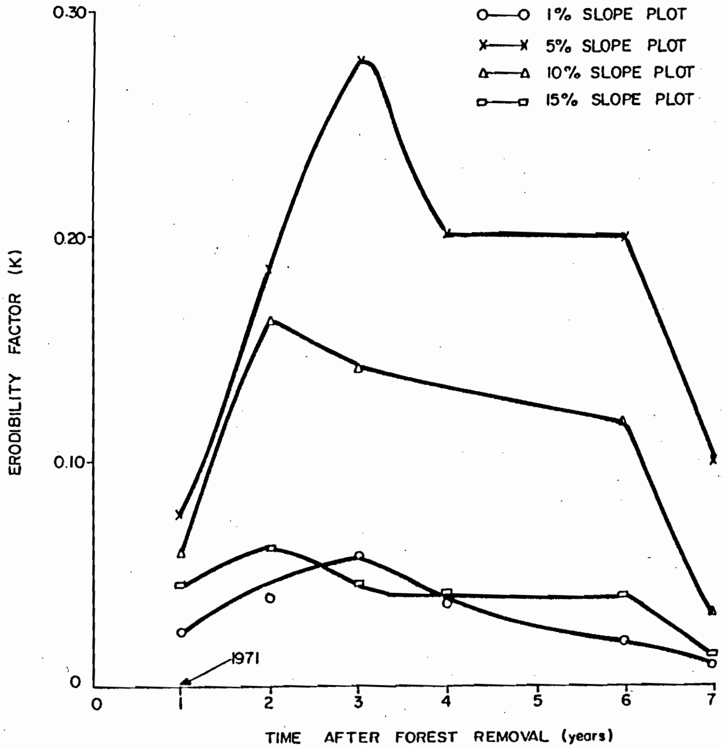


**Fig. 3** Changes in erodibility of an alfisol in southwest Nigeria with time (Lal, 1981a).

Anastase, 1977; Poto, 1979; Ajunwon, 1981; Food and Agriculture Organization, 1977), by obtaining estimates of soil erodibility (K) from the Wischmeier *et al.* (1971) nomogram, and by estimating rainfall erosivity either from rainfall amount (Roose, 1977), from available records of rainfall intensity (Anastase, 1977; Ajunwon, 1981) or by using a modified Fournier aggressivity index (Food and Agriculture Organization, 1977). These maps are computed on the assumption that different parameters of the Universal Soil Loss Equation are applicable. Although this type of data can have some useful applications, the information can be grossly misleading and can result in erroneous interpretations. It is important not to devote additional time and financial resources to applying empirical models developed elsewhere, but to concentrate our resources in understanding the basic processes of soil erosion and in developing appropriate techniques to control them. The rational analysis of erosion requires conceptual understanding of an ecosystem, and the magnitude of alterations and interactions among various environmetal factors by change in land use. Unthinking adoption of empirical models developed for different environments are no substitute for basic data.

## DENUDATION RATES IN MAJOR RIVER BASINS

Erosion rates for major river basins in Africa have been reported by

Balek (1977), Ongweny (1978), Ward (1980), Rodier *et al.* (1981), and Lahlou (1982). Some of the data are at least 20 years old and were certainly obtained before the implementation of large-scale land development schemes. The estimates of sediment load reported are, therefore, in many cases low and obsolete. For example, the earlier data indicate annual erosion rates of 0.008 mm for the Niger, 0.015 mm for the Congo and Niger-Benue, and 0.036 mm for the Benue river basins (Balek, 1977). Barber (1983) also observed that for some Kenyan rivers the natural erosion rates are low at 0.02-0.03 mm $year^{-1}$ for humid regions with volcanic rocks and 0.04-0.12 mm $year^{-1}$ for the basement complex in semiarid regions. The accelerated erosion on arable land, however, can be as high as 0.6-16 mm $year^{-1}$ (Dunne & Ongweny, 1976; Barber, 1983).

In addition to the effects of rapidly changing land-use patterns, the sediment load from large catchments also depends on catchment size, slope and physiography, and parent material. Oyebande (1981) observed a decrease in sediment yield with an increase in the drainage area for some Nigerian river basins. For example he reported an annual sediment yield of 377 t $km^{-2}$ for drainage areas of less than 10 000 $km^2$, 119 t $km^{-2}$ for 10 000-50 000 $km^2$, 77 t $km^{-2}$ for 50 000-100 000 $km^2$ and 44 t $km^{-2}$ for drainage areas exceeding 100 000 $km^2$. On the contrary, the data of Edwards & Blackie (1981) regarding the sediment yield of some Kenyan rivers and that of Rapp *et al.* (1972) for seven basins in Tanzania do not show any clear relationship between sediment yield and basin area. Some researchers have also related suspended sediment yield to other controlling factors, including mean annual runoff (Edwards, 1979), a rainfall aggressivity index (Demmak, 1982), land use (Lal, 1981c; Dunne, 1979), and vegetation cover (Starmans, 1970; Roose, 1977; Balek, 1977).

It is, in fact, difficult to relate sediment yield to any one controlling environmental factor. Fournier (1960, 1966), for example, observed that suspended sediment yield was related to three environmental factors, namely, mean altitude, mean slope, and an index of rainfall aggressivity, viz.

$$\log E = 2.65 \log p^2/P + 0.46 \log H \tan \bar{\phi} - 1.56$$

where E = suspended sediment yield in t $km^{-2} year^{-1}$; H = mean altitude; $\bar{\phi}$ = mean slope; p = monthly rainfall in mm; and P = annual rainfall in mm. Solomon (1967) developed a relationship between rainfall, evaporation and runoff for equatorial Africa. Yet another empirical relationship was developed by Jansen & Painter (1974) for humid regions relating annual sediment yield to four controlling factors, viz.

$$\log S = 4.4 + 1.5 \log D - 0.3 \log A + 0.3 \log R - 3.4 \log T$$

where S = sediment yield (t $km^{-2} year^{-1}$); D = annual runoff discharge ($m^3 km^{-2}$); A = basin area ($km^2$); R = relief-length ratio (m $km^{-1}$); and T = mean annual temperature (°C).

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One of the weakest links in any attempt to relate the sediment load of a river to the local rates of erosion over the catchment is the lack of information on the "delivery ratio". Information relating sediment delivery ratio to catchment size, parent material, relief, and the predominant land-use is needed for the different ecological regions of tropical Africa.

## LAND USE AND SOIL EROSION

Every year, vast areas of forested land are being converted to arable land use in an attempt to meet the demand for food, fibre, feed, and fuel. The change in land use and the range of cultural practices of soil and crop management used have drastic effects on erosion and sediment yield.

### *Deforestation*

Soil erosion becomes severe whenever the natural vegetation is modified or removed creating an ecological imbalance. Roose (1970), working in the humid regions of Ivory Coast, observed that surface runoff under forest cover represented only 1.5% of the 1750 mm of annual rainfall. Interflow, however, formed a major component of the water balance and amounted to 500-600 mm $year^{-1}$. Deforestation increased surface runoff and sediment yield by 50 and 1000 times respectively, compared to the forested control. Soil erosion from arable land was 20-90 t $ha^{-1}year^{-1}$ in comparison with 20-450 kg $ha^{-1}year^{-1}$ under forest. Similar effects of deforestation have been reported from East Africa by Pereira (1973), Rapp (1977), Robinson (1978), and Christiansson (1978). In Kenya, Dunne (1979) reported that sediment yield from agricultural and grazed catchments was significantly more than from partially or completely forested catchments (Table 2). In northern Nigeria, Kowal (1972a,b) observed soil erosion rates of 3-18 t $ha^{-1}year^{-1}$ from arable land in comparison with zero erosion from plots where the natural vegetation cover was not disturbed. Lal (1981c) reported that the method of deforestation had a significant effect on runoff and sediment discharge from agricultural catchments. The least runoff

**Table 2** Land use and sediment yield in Kenya (Dunne, 1979)

| | $R^2$ |
|---|---|
| *Forest* | |
| $SY = 1.56\ Q^{0.46}\ S^{-0.03}$ | 0.98 |
| $SY = 2.67\ Q^{0.38}$ | 0.98 |
| *Forest > agriculture* | |
| $SY = 1.10\ Q^{1.28}\ S^{0.05}$ | 0.76 |
| *Agriculture > forest* | |
| $SY = 0.14\ Q^{1.48}\ S^{0.51}$ | 0.74 |
| *Rangeland* | |
| $SY = 4.26\ Q^{2.17}\ S^{1.12}$ | 0.87 |

SY = Sediment yield (t $km^{-2}$ $year^{-1}$). Q = Mean annual runoff (mm). S = Relief.

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and erosion were observed from plots cleared by traditional methods and by manual tools. Mechanized clearing increased runoff and soil erosion by several orders of magnitude more than manual clearing methods.

In view of the large scale deforestation currently occurring in the tropics, more data are needed to quantify the effects of methods of deforestation and of change in land use on runoff and sediment yield for different soils and ecological environments.

*Grazing*

Uncontrolled grazing is obviously an important factor determining the magnitude of soil erosion. Grazing pressure influences the vegetation cover and the water intake rate through its effect on soil compaction. Pereira *et al.* (1967) working in Kenya observed that the trampling of 20 yearling beasts on 1 acre for 2 days produced severe runoff, even from a paddock completely covered by leys. In Cameroon, Hurault (1968) observed that even the low stocking rate of one head of cattle per 10 ha accelerated soil erosion on the clayey soils of the high plateau of Adamawa. In Kenya, Dunne (1979) observed maximum sediment yields from those catchments with heavy grazing pressure. In the steeplands of Machakos, Kenya, Thomas *et al.* (1980) observed that well-maintained pasture had slight or tolerable levels of erosion. With uncontrolled grazing on degraded lands, however, erosion increased by 50 times (Table 3). Quantitative data of this type are needed for other soils and environments of Africa to assist planners to develop appropriate land use systems.

*Fire*

Fire is an important ecological factor in tropical Africa. Fire accelerates soil erosion directly by denuding the vegetation cover and indirectly by affecting the water infiltration rate of soil. Bare soil surfaces are easily compacted by raindrop impact. Fire also destroys soil fauna that keep the soil porous. In spite of its ecological importance, there are few quantitative data concerning the effects of frequency and intensity of burning on soil erosion. Roose & Asseline (1978) observed that burning the crop residue increased soil erosion several fold when compared with an unburnt control.

**Table 3** Effect of grazing on soil erosion in Machakos, Kenya

| Land use | Soil loss (mm $year^{-1}$) | Ratio |
|---|---|---|
| Degraded grazing land | 4.5 | 50 |
| Cultivated land | 1.3 | 15 |
| Good grazing land (bush and woodland) | 0.07 | 1 |

Source: Thomas *et al.* (1980).

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*Cultural practices and cropping systems*

Plantation crops and those that provide a continuous ground cover cause less soil erosion than seasonal crops that require frequent seedbed preparation. Pereira (1973) observed that risk of runoff and soil erosion from a tea plantation was less than from arable land. For arable land use, crop rotations and cropping sequences also affect the magnitude of soil erosion through their effect on the ground cover and on soil structure. In general, however, erosion is affected more by "how" a crop is grown than by "what" crop is grown. Soil management, therefore, seems to be a more important determinant of erosion than crop management.

Many researchers in tropical Africa have indicated the greater dangers of accelerated erosion associated with continuous and intensive cultivation by mechanized farm operations than with traditional farming (Fauck *et al.*, 1967; Roose, 1967; Charreau, 1969; Kowal, 1972a,b; Lal, 1976; Stocking, 1983). Regrettably, however, food production cannot be increased substantially and immediately by the extensive and less productive traditional farming methods.

Developing cropping systems that ensure continuous vegetal cover is an important management principle (Wilkinson, 1975b; Elwell & Stocking, 1976; Aina *et al.*, 1977; Moore *et al.*, 1979; Norén & Nordén, 1983). It is generally agreed that biological methods of erosion control are more effective and economic than engineering techniques of land forming (Roose & Lelong, 1976; Collinet & Valentin, 1979). Many researchers have also observed that soil erosion can be effectively controlled on arable lands with gentle to rolling slopes by application of 4-6 t $ha^{-1}$ of crop residue mulch (Othieno, 1975; Baffoe-Bonnie & Quansha, 1975; Lal, 1976; Roose, 1977; Roose & Asseline, 1978). One of the ways to procure mulch and to implement biological methods of erosion control is through the no-till system of soil management (Lal, 1984a).

## THE ECONOMIC EFFECTS OF SOIL EROSION

Soil erosion results in both on-site and off-site damage. On-site erosion affects crop growth and yield both directly and indirectly. Among the direct effects are poor seedling establishment, waterlogging and crop burial (Figs 2 and 3). Indirectly, soil erosion affects crop growth by altering the physical and nutritional properties of the soil and by reducing the fertilizer use efficiency. Fournier (1963) observed a decrease in the yield of millet due to soil erosion in the Niangoloko region of Upper Volta. He calculated that an increase in the annual rate of erosion from 143 to 1318 t $km^{-2}$ decreased millet yield from 727 to 352 kg $ha^{-1}$. In addition to the loss of fertile topsoil, high rates of water runoff increased the frequency, duration and intensity of drought stress. Rehm (1978) reported that in Cameroon the removal of 2.5 cm of topsoil caused a 50% drop in maize yield and that the exposed subsoil became completely unproductive when 7.5 cm of soil was removed. In western Nigeria, Lal (1976) reported a maize yield reduction of 23% after 2.5 cm of soil was artificially removed.

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In another study, Lal (1981a) observed an exponential decline in the grain yield of maize and cowpea with increases in cumulative soil erosion. Mbagwu *et al.* (1984) studied the effects of topsoil removal on maize and cowpea grain yield with variable rates of N and P application on an ultisol in southeastern Nigeria (Onne) and two alfisols in southeastern Nigeria. Both maize and cowpea yields were drastically reduced with removal of 5 cm of topsoil. None of the fertilizer combinations used was an effective substitute for topsoil loss, especially for the ultisol.

Reservoir sedimentation, another indirect measure of soil erosion, is one of the major off-site damages caused by accelerated soil erosion. Studies of reservoir sedimentation in Tanzania are reported by Rapp *et al.* (1972), Stromquist (1981) and Christiansson (1981). In the Dodoma and Arusha Districts, erosion causes high rates of sedimentation in reservoirs (Rapp, 1975). Chakela (1981) reported that reservoir sedimentation rates in Lesotho vary from [illegible] to 25 cm $m^{-2} year^{-1}$, corresponding to a sediment yield of [illegible]-1800 t $km^{-2} year^{-1}$. The sedimentation rate in Ikawa reservoir in Tanzania measured from 1957 to 1969 indicated the accumulation of [illegible] million $m^3$ of sediment with a 39.2% loss in reservoir capacity. The mean soil denudation rate over the catchment was estimated to be 0.195 mm $year^{-1}$. In Nigeria, Oyebande (1981) estimated the annual sedimentation in 13 reservoirs to range from 0.05 to [illegible] million tonnes. The associated annual loss in storage capacity was estimated to be 0.02 million $m^3$ to 10.5 million $m^3$. Little is known regarding the environmental pollution effects of erosion in tropical Africa, e.g. eutrophication of natural waters and the pollution hazard.

## SOIL EROSION ESTIMATION

Field experimentation is supposedly an expensive and time consuming exercise, but whatever the cost and the capital investment, there is no substitute for field data. Many researchers have, however, used indirect methods of obtaining estimates of erosion risk. The Universal Soil Loss Equation has been widely used (Roose, 1977; Food and Agriculture Organization, 1978), but regrettably without evaluating its applicability for the wide range of soils and environments in tropical Africa. In addition, models have also been developed to estimate erosion risk from a knowledge of soil and environmental characteristics (Stocking, 1973, 1980; Elwell, 1978). Some of these models can be adapted for other regions of tropical Africa. Attempts have also been made to assess erosion hazard by using soil surveys (Heusch, 1980) and by monitoring creep using fluorescent dyes (Lewis, 1981).

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## RESEARCH PRIORITIES

In spite of the rather impressive body of data collected, it is apparent that our conceptual understanding of the problem of soil erosion in tropical Africa is far from being complete. Researchers have failed to analyse soil erosion as an "ecological" problem with a "holistic" approach. There are also specific problems with the available research information that make meaningful interpretation difficult. These problems include:

(a) *Data reliability:* There is no substitute for good reliable data. In the long run, "guestimated" research information is bound to do more harm than good.

(b) *Standardization of methodology:* Erosion research techniques are still more of an art than a science. The data obtained by different methodologies cannot be easily compared. The methodology adopted should be standardized, simple and direct.

(c) *Instrumentation:* An appropriate level of instrumentation is the one that permits local fabrication and servicing.

In addition, there are striking knowledge gaps in our understanding of erosion processes and their control. Additional research is needed for the following:

(a) *Sediment source:*

(i) *Erodibility:* There is a need to define and quantify the susceptibility of various soils to erosion in relation to their physical, chemical, and biological properties. The mechanisms, concepts, and measuring techniques involved are different for "splashability", "rillability", "gullibility" and susceptibility to mass movement.

(ii) *Gully erosion:* In comparison with sheet erosion, our understanding of gully erosion and mass movement processes is sketchy and incomplete.

(b) *Sediment transport and delivery:*

(i) *Sediment transport vs. sediment delivery:* The sediment delivery ratio is a major unknown in most studies. In addition, the term "delivery ratio" is frequently used in a rather general context. It must be linked to specific land use conditions, and to catchment characteristics. It is important to define "delivery ratio" in terms of catchment size and land use systems.

(c) *Models:* Models are not a substitute for good reliable data. They are good tools for extrapolating the data within the "limits" of experimentation and for identifying knowledge gaps. The applicability of a model beyond the limits of its experimental conditions is doubtful and often wasteful. No model should be allowed to become an obstacle to understanding the basic concepts and in solving the practical problems of the region.

(d) *Erosion control:*

(i) *Economic consequences:* Soil erosion and its effects must be expressed in monetary terms related to loss in productivity, environmental damage, and damages to infrastructure and civil properties.

(ii) *Land use:* Scientists have a responsibility to develop technology for meeting the needs and aspirations of the community. It is the lack of appropriate technology that leads to land misuse.

(iii) *Prevention vs. cure:* It is important to identify the land use and soil management systems that "prevent" erosion. From the land use point of view, the technology recommended must not be a "quantum" jump or of a revolutionary nature. It must be based on gradual evolution and improvements in existing technology. To be successful a technology must be technically

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feasible, ecologically compatible, economically viable, socially acceptable, and politically permissible.

(iv) *Restoration of degraded lands:* While taking steps to prevent new erosion, it is also important to develop methodologies for restoring land that has been degraded by accelerated soil erosion.

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*Received 24 September 1984; accepted 14 November 1984.*

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