Challenges in African Hydrology and Water Resources (Proceedings of the Harare Symposium, July 1984). IAHS Publ. no. 144.

Mulch requirements for erosion control with the no-till system in the tropics: a review

R. LAL
International Institute of Tropical Agriculture, Ibadan, Nigeria

ABSTRACT Accelerated soil erosion is one of the factors responsible for rapid decline in crop yield on arable lands in the tropics even within a few years of deforestation and new land development. Engineering practices of water runoff management are expensive to install and their effectiveness depends on regular maintenance. Research in West Africa and elsewhere in the tropics has indicated the potential of biological control measures associated with mulch farming techniques and of no-till system in reducing runoff and soil erosion to within tolerable limits. The magnitude of soil loss reduction and of water conservation produced by the no-till system, however, depends on the quantity and durability of the crop residue mulch. The "mulch factor" also depends on slope gradient, on soil erodibility and hydrological properties, and on crop characteristics. Biological control measures and crop residue mulches influence runoff and soil erosion directly by preventing drop impact, and indirectly by improving hydrological properties through their effects on soil structure, moisture regime, and water transmission properties. For slopes ranging between 2 and 20%, mulch rates of 6-8 t ha^{-1} have been found to be adequate if regularly maintained. The effective mulch rate to control soil erosion was generally less with the no-till than with conventional methods of seed-bed preparation. Mulch rate was also less for crops that develop a rapid canopy cover close to the soil surface. Results from the tropics are reviewed in terms of their implications for soil and crop management systems.

Aperçu des besoins en paillis dans la lutte contre l'érosion en système de non-travail du sol dans les régions tropicales

RESUME L'érosion accéléré du sol est un des facteurs responsable de la baisse rapide de la productivité des sols arables dans les tropiques, même dans les quelques années qui suivent la déforestation et la mise en valeur de nouveaux terrains. Les pratiques d'ingénierie d'aménagement de l'écoulement sont généralement trop chères et leur efficacité dépend d'une maintenance régulière. La recherche en Afrique de l'Ouest et ailleurs soulignent le potentiel des mesures de contrôle biologique, comprenant des techniques de déchaumage, et du système de non-travail du sol dans la réduction au niveau tolérable du ruissellement et de l'érosion du sol. Cependant, l'ampleur de la réduction des pertes de sol et de la conservation des eaux obtenue avec le système de non-travail du sol dépend de la qualité et de la durabilité de la couche protectrice de paillis. Le "facteur mulch" dépend aussi de la pente (inclinaison, longueur et forme), du sol (e.a. l'érodibilité, propriétés hydrologiques) et des caractéristiques de la culture (le couvert végétal, système racinaire, durée, etc). Les techniques de controle biologique et de paillage influencent le ruissellement et l'érosion directement en prévenant l'impact des gouttes et indirectement en améliorant les propriétés hydrologiques à travers leurs effets sur la structure du sol, sur le régime d'humidité et sur les propriétés de transmission d'eau. Pour des pentes entre 2 et 20%, des quantités de 6 à 8 t ha^{-1} sont adéquates, si la couche est régulièrement maintenue. En général, les besoins en mulch sont moins dans le système de non-travail du sol que dans les méthodes conventionelles de culture. Le développement rapide d'un couvert végétal, près de la surface du sol, réduit aussi la quantité requise de paillis. Les résultats obtenus sous les tropiques sont évalués sur leurs implications dans les systèmes d'aménagement du sol et des cultures.

INTRODUCTION

Whereas the lack of a protective vegetation cover at the onset of monsoon rains causes severe erosion in semiarid regions and in the Sahel (Rapp *et al.*, 1972; Adu, 1972; Talbot & Williams, 1978; Barth, 1978; Fauck, 1977), unprecedented rates of deforestation and the use of heavy equipment for land clearing and subsequent cultivation are responsible for accelerated soil erosion in the forest zone of sub-humid and humid climates (Wilkinson, 1975; Greenland & Lal, 1977; Dunne, 1977; 1979; Lal, 1976, 1981). In the humid zone, erosion is generally of no consequence on forested lands and on farmland cultivated by traditional methods (Lal, 1981). Two questions of immediate concern are firstly, how serious is the soil erosion, and secondly, how can it be controlled while permitting an intensive land use.

THE SEVERITY OF EROSION IN TROPICAL AFRICA

Some soil erosion is inevitable even in an undisturbed environment, because it is a natural process. Soil erosion is severe when the rate of soil removal exceeds the rate of new soil formation. The productivity of the exposed subsoil becomes uneconomic, even with improved systems of soil and crop management and with additional agronomic inputs. These criteria do not involve the off-site damages and the effects of erosion on the environment.

The rate of soil formation is difficult to determine, and little is known about it for soils in Africa. Even less is known concerning the effects of erosion on the productivity of African soils. The

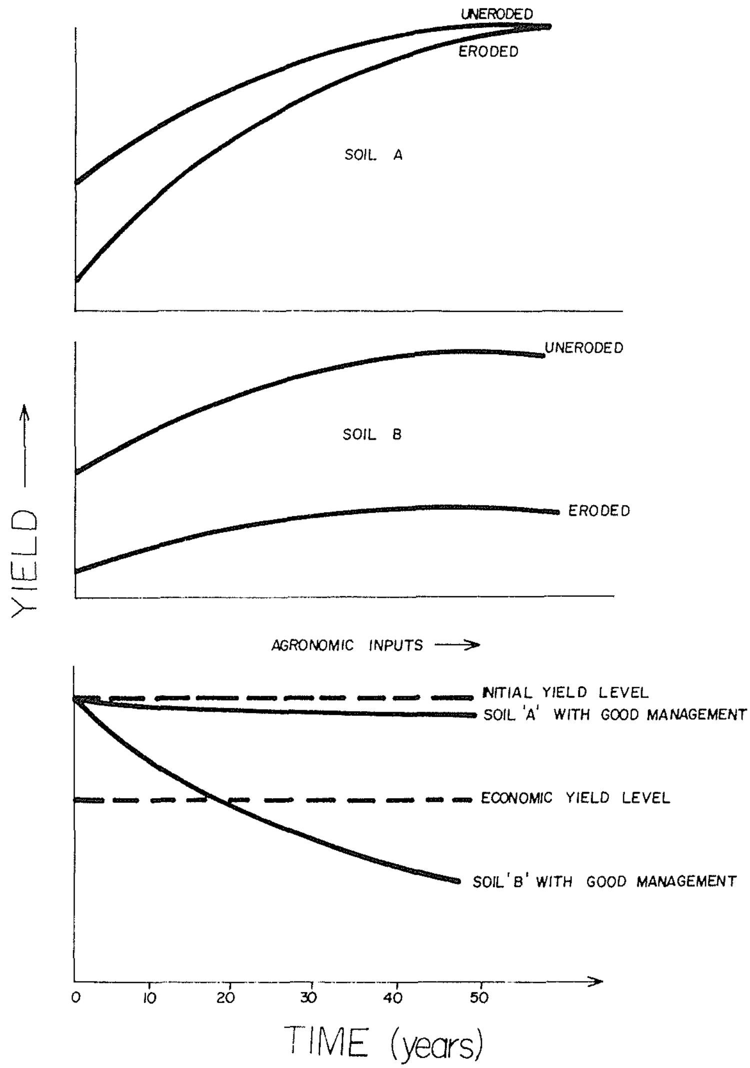

FIG.1 Schematic comparative analyses of the response of eroded and uneroded soils to agronomic inputs and improved technology (modified from Shrader et al., 1963).

latter depends on many factors including the distribution of plant nutrients in the soil profile, effective rooting depth, the physical, chemical and biological properties of the subsoil, and the availability of agronomic/technological strategies to manage subsoils. A qualitative assessment of characteristics of soil B shown in Fig.1 shows the yield to be more susceptible to erosion than in the case of soil A, even for the same magnitude of soil erosion. For the purposes of planning for future land development, it is important to delineate regions predominantly containing soils of type B and to ensure that these soils are left undisturbed awaiting further technological developments.

This over-generalization should, however, not be interpreted to imply that soils of type A can be subjected to indiscriminate land use regardless of the climatic constraints. No soil is durable against mismanagement. What it means is that the severity of erosion risks and the probability of losing soil A as a resource are less than for soil B.

TERRACING

Technological measures for the management of marginal lands (i.e. category B soils) can be of two types. For those soils with relatively favourable subsoil characteristics, land forming is possible, provided that agronomic practices of nutrient management are developed and are easily and economically available. In south and southeast Asia bench terraces have been used for centuries in conjunction with a very intensive land use. Although paddy cultivation is a rather special case, because continuous inundation drastically alters the root-zone environment, the art of managing exposed subsoil has also enabled Asian farmers to use sloping lands for an intensive cultivation of upland crops. The decision is made on the relative merits of managing undisturbed sloping land for cultivation of upland crops and risking the loss of nutrient rich surface soil, or developing bench terraces as water control devices and developing appropriate agronomic practices to manage an infertile exposed subsoil. Learning the art of managing the "subsoil" is extremely important regardless of the approach adopted.

The bench terraces used in south and southeast Asia are different from the graded channel terraces commonly employed on mechanized farms in tropical Africa. Whereas the Asian terraces are primarily water control devices constructed to ensure an equitable water distribution for paddy cultivation the principal function of graded channel terraces is to control soil erosion. The former terraces are 3-4 m wide and nearly flat. They are regularly and intensively maintained, and there is no risk of soil erosion. The graded channel terraces established for mechanized arable cultivation are generally wider, with inter-terrace widths of 20-30 m depending on slope, and are rarely flat. These terraces are constructed to prevent accumulation of runoff on long slopes and to reduce velocities of flow, ensuring its comparatively safe disposal into specially devised grass waterways. They are effective if the predominant slope is gentle to medium, and if terrace channels are regularly maintained. The data shown in Table 1 relate to an exceptionally intense rainstorm (Fig.2) recorded at IITA, Ibadan, and indicate the lack of effectiveness of graded channel terraces at slope gradients exceeding 5%. These intense storms with a return period of about 5-10 years cause enormous damage to arable lands and urban structures. Inter-terrace soil management to reinforce mechanical structures is, therefore, essential for effective soil and water conservation on these erodible soils in harsh environments.

MULCH FARMING

Accelerated soil erosion is a symptom of land misuse and soil

TABLE 1 Erosion from 10 and 20 m inter-terrace widths of varying slope gradient (IITA, Ibadan) (in t ha^{-1})

Slope	*Slope length:*	
%	*10 m*	*20 m*
1	*0.15*	*0.13*
5	*16.10*	*1.90*
10	*24.00*	*18.01*
15	*60.11*	*59.10*

mismanagement practices. Sloping lands with soils highly susceptible to severe erosion are more suited to perennial crops than to arable land-use. With an ever increasing land shortage, however, even marginal lands are being subjected to intensive arable use.

Mulching has proved to be an effective technique in many ecological environments on a wide range of soils. In East Africa, mulches are widely recommended for erosion control on tea estates (Shaxson, 1975; Othieno, 1975; Othieno & Laycock, 1977). Roose (1975) and Roose & Asseline (1978) demonstrated that mulching of pineapple plots in Ivory Coast was the most effective means of combating erosion

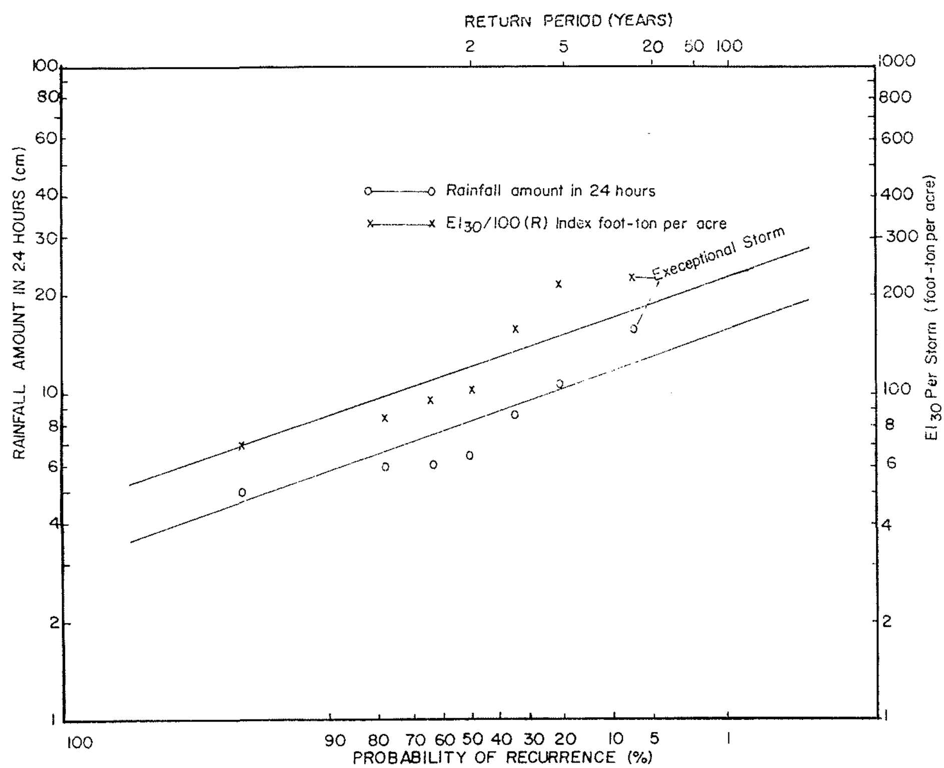

FIG.2 Return period and frequency of the EI_{30} index (R) and of rainfall intensity for a storm at Ibadan (modified from Lal et al., 1980).

(Table 2). In the Sudano-Sahelian plains of northern and central Ivory Coast, Collinet & Valentin (1979) concluded that straw mulching is the only entirely effective technique for maintaining high infiltration rates. Mensah-Bonsu & Obeng (1979) concluded from plot measurements at Kumasi, Ghana, that compared with bare fallow,

TABLE 2 Effect of residue management on soil erosion (t ha^{-1}) from pineapples in Ivory Coast (adapted from Roose & Asseline, 1978)

Slope (%)	*Bare soil*	*Soil erosion under different treatments: Residue burnt*	*Incorporated*	*Mulch*
4	*15*	*0.2*	*0.03*	*0.001*
7	*102*	*3.8*	*0.06*	*0.0001*
20	*253*	*16.7*	*9.7*	*0.007*

mulching reduced runoff by between 11 and 35 times and erosion by between 188 and 750 times. Similar results have been reported by Hudson (1971) for Zimbabwe and Lal (1976) for southwest Nigeria.

AGRONOMIC PRACTICES TO PROCURE MULCH

Besides being technically viable, any successful cultural practice must also meet the demands of ecological, climatic, and social constraints. Mulch rates of 4-6 t ha^{-1} from a single crop are difficult to procure, even in a labour intensive economy. Appropriate methods must, therefore, be developed to procure adequate amounts of residue mulch.

TABLE 3 Some cover crops used for soil and water conservation in tropical Africa

Cover crop	*Country of use*	*Reference*
Panicum coloratum	*Kenya*	*Thomas (1975)*
Psophocarpus palustris	*Nigeria*	*Okigbo & Lal (1977)*
Stizolobium deeringianum	*West Africa*	*Wilson & Lal (1984)*

A variety of creeping and low growing legumes are recommended as cover crops for erosion control on steep lands (Table 3). A study of paired watersheds (5 ha) at Ibadan, Nigeria, has, for example, clearly demonstrated the effectiveness of a cover of *Mucuna utilis* in runoff control (Fig.3).

Merits of no-till farming for bio-structurally active soils have been documented for some soils in tropical Africa (Lal, 1983). In Ghana, Baffoe-Bonnie & Quansah (1978) reported from their studies

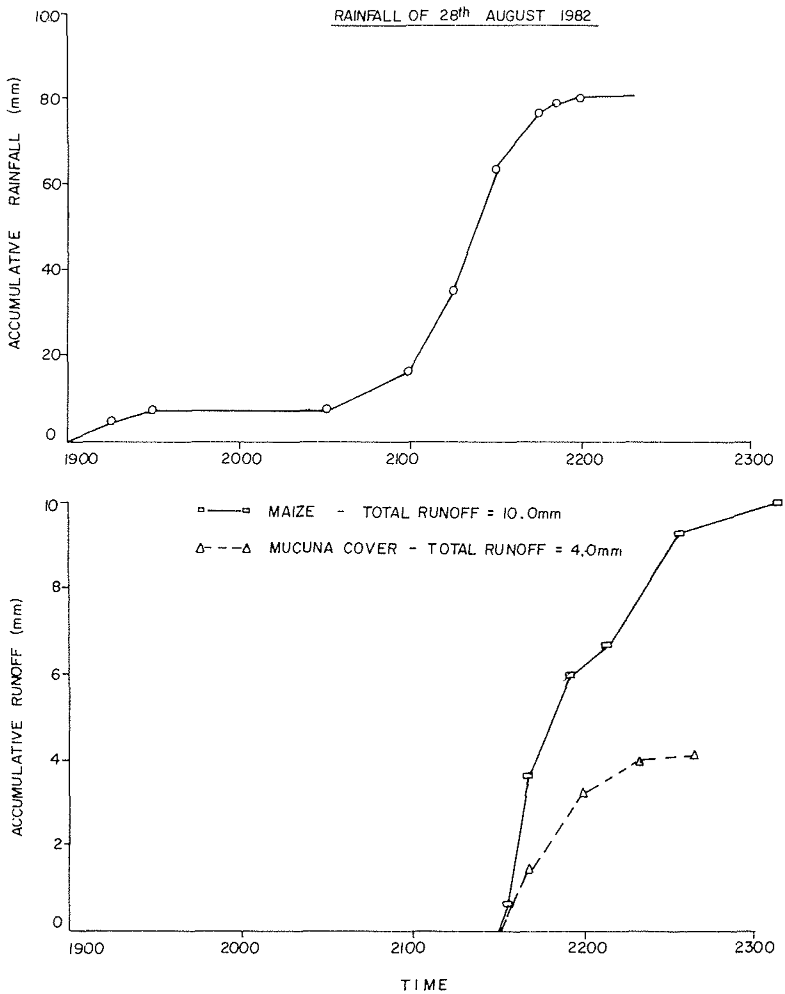

FIG.3 Runoff hydrographs from two catchments on alfisols growing maize and Mucana cover.

near Kumasi that reduced tillage caused the least compaction, maintained porosity, and suffered the least soil and water losses. Mensah-Bonsu & Obeng (1979) also observed in Ghana that, in comparison with conventional ploughing, no-tillage reduced runoff by between 70 and 90% and soil erosion by 97%.

The effectiveness of no-till for erosion control, however, depends on the quantity of crop residue mulch. Soil erosion and water runoff losses can be severe if a no-till system is adapted without an adequate quantity of crop residue mulch. Soil erosion and water runoff losses can be severe if a no-till system is adapted without an adequate quantity of crop residue mulch (Charreau, 1977). The data in Table 4 show that for some alfisols in a subhumid environment, effective erosion control with a no-till system is achievable with a crop residue mulch of 2-4 t ha^{-1} per crop.

The mulch requirements for a no-till system applied to a wide range of soils, slope gradients, crops and ecological environments are hard to generalize. This is the type of adaptive research that is needed for regional soils, crops, and environments. Appropriate farming systems have to be developed to meet the mulch requirements for soil and water conservation, and for alternative uses. Mulch can be procured from the previous crop residue, by cut and carry, by growing suitable cover crops, and from agroforestry. Soil and crop management requirements differ widely among these systems.

TABLE 4 Effects of different mulch rates on runoff (mm) and soil erosion ($t\ ha^{-1} season^{-1}$) under no-till maize from an alfisol at Ibadan

Mulch rate	*Runoff (mm)*	*Soil erosion ($t\ ha^{-1}$)*
0	*56.4*	*1.50*
1	*50.8*	*0.42*
2	*52.9*	*0.49*
3	*46.7*	*0.44*
4	*30.1*	*0.32*
Ploughed	*79.0*	*0.62*
Ploughed bare	*115.0*	*1.00*

Data refer to a plot 10 x 2 m with a gradient of 10% and are for the second season, 1981.

APPLICATION OF A MECHANIZED NO-TILL SYSTEM IN THE TROPICS

No-till systems can be readily adapted for crop production by small-scale farmers providing herbicides are easily and economically available. For large-scale mechanized agriculture, however, the choice of appropriate farm equipment is important. Excessive use of heavy equipment can cause severe compaction of surface soil leading to low infiltration, high water runoff, poor and an uneven crop stands, and low uneconomic returns. Soil compaction can be avoided by the selection of appropriate crop rotations, ensuring an adequate amount of crop residue mulch, reducing the frequency of traffic by farm vehicles to an absolute minimum, planning the timing of farm operations, and by using suitable combinations of seeding and spraying equipment.

Measures for preventing soil erosion and compaction are to be preferred over the curative techniques. The latter are too expensive, are either temporary measures or ineffective, and are often too late to prevent severe soil degradation. Mechanized no-till systems should incorporate the concept of "zonal tillage", with guided or controlled traffic. In addition to "seedling" and "soil and water conservation" zones, sloping land should also have a "traffic" zone. The farm equipment should always use the same tracks so that soil compaction is limited to this zone.

CONCLUSION

The severity of soil erosion depends on soil, crop, and management. The most important parameter of soil erosion is the anthropogenic factor. Irrespective of the erosion techniques adopted, mastering the art of managing subsoil fertility is very important and relevant in these times of ever increasing land shortage. Mulch requirements for a no-till system vary among soils, crops, and agro-ecologies and adaptive research to define these requirements should be given a high priority.

REFERENCES

Adu, S.V. (1972) Eroded savanna soils of the Navrongo-Bawku area, northern Ghana. *Ghana J. Agric. Sci.* 5, 3-12.

Baffoe-Bonnie, E. & Quansah, C. (1978) The effect of tillage on soil and water loss. *Ghana J. Agric. Sci.* 8, 191-195.

Barth, H.K. (1978) Extent and effect of culturally-induced soil erosion in the interior delta of the Niger and Mali. In: *Contributions to the Geomorphology of the Arid Zone. Z. für Geomorphologie* Supplementband 30, 39-54.

Charreau, C. (1977) Some controversial technical aspects of farming systems in semi-arid West Africa. In: *Proc. Int. Symp. on Rainfed Agric. in Semi-arid Regions* (Univ. Calif., Riverside), 313-360.

Collinet, J. & Valentin, C. (1979) Analysis of the different factors affecting surface hydrodynamics, new prospects and agronomic applications. *Cahiers ORSTOM, Ser. Pédol.* 17, 283-328.

Dunne, T. (1977) Studying patterns of soil erosion in Kenya. *FAO Soils Bull.* 33, 109-122.

Dunne, T. (1979) Sediment yield and land use in tropical catchments. *J. Hydrol.* 42, 281-300.

Dunne, T., Dietrich, W.E. & Brunengo, M.J. (1978) Recent and past rates of erosion in semi-arid Kenya. *Z. Geomorphol.* Suppl. 29, 91-100.

Fauck, R. (1977) Soil erosion in the Sahelian zone of Africa: its control and its effect on agricultural production. In: *Proc. Int. Symp. on Rainfed Agric. in Semiarid Regions* (Univ. Calif., Riverside), 371-397.

Greenland, D.J. & Lal, R. (eds) (1977) *Soil Conservation and Management In The Humid Tropics.* Wiley, Chichester, UK.

Hudson, N.W. (1971) *Soil Erosion.* Batsford, UK.

Lal, R. (1976) *Soil Erosion Problems on Alfisols in Western Nigeria and Their Control.* IITA Monograph 1, IITA, Ibadan, Nigeria.

Lal, R. (1981) Soil erosion problems on an Alfisol in western Nigeria VI. Effects of erosion on experimental plots. *Geoderma* 25, 215-230.

Lal, R. (1983) *No-till Farming.* IITA Monograph 3, IITA, Ibadan, Nigeria.

Lal, R., Lawson, T.L. & Anastase, A.H. (1980) Erosivity of tropical rains. In: *Assessment of Erosion* (ed. by M.De Boodt & D.Gabriels), 143-153. Wiley, Chichester, UK.

Mensah-Bonsu & Obeng, H.B. (1979) Effects of cultural properties on soil erosion and maize production in the semi-deciduous rainforest and forest-savanna transitional zones of Ghan. In: *Soil Physical Properties and Crop Production in the Tropics* (ed. by R.Lal & D.J.Greenland), 509-519. Wiley, Chichester, UK.

Okigbo, B.N. & Lal, R. (1977) Role of cover crops in soil and water conservation. *FAO Soils Bull.* 33, 97-108.

Othieno, C.O. (1975) Surface runoff and soil erosion on fields of young tea. *Trop. Agric.* 52, 299-308.

Othieno, C.O. & Laycock, D.H. (1977) Factors affecting soil erosion under tea fields. *Trop. Agric.* 54, 323-331.

Rapp, A., Berry, L. & Temple, P. (1972) Studies of soil erosion and sedimentation in Tanzania. *Geographiska Annala* 54A, 105-379.

Roose, E.J. (1975) Natural mulch or chemical conditioner for reducing soil erosion in humid tropical areas. *Special Publ. Soil Sci. Soc. Am.* 7, 131-138.

Roose, E.J. & Asseline, J. (1978) Measurement of erosion phenomena under simulated rainfall at Adiopodoume, solid and soluble loads in runoff water from bare soil and pineapple plantations. *Cahiers ORSTOM, Ser., Pédol.* 16, 43-72.

Shaxson, T.F. (1975) Soil erosion, water conservation, and organic matter. *World Crops* 27, 6-10.

Shrader, W.D., Johnson, H.P. & Timmons, J.F. (1963) Applying erosion control principles. *J. Soil Wat. Conserv.* 18, 195-199.

Talbot, M.R. & Williams, M.A.J. (1978) Erosion of fixed dunes in the Sahel, Central Niger. *Earth Surf. Processes* 3, 167-114.

Thomas, D.B. (1975) Landuse and soil erosion of Kalama location, Machakos District. *Kijani* 1, 16-17.

Wilkinson, G.E. (1975) Rainfall characteristics and soil erosion in the rainforest area of western Nigeria. *Expl. Agric.* 11, 247-255.

Wilson, G.F. & Lal, R. (1984) New approaches towards soil and water conservation in tropical Africa. In: *Land Clearing and Development in the Tropics* (ed. by R.Lal, P.A.Sanchez & R.W.Cummings, A.A.Balkema, Rotterdam, The Netherlands (in press).