PN-AAT-498

COOPERATIVE AGREEMENT ON HUMAN SETTLEMENTS AND NATURAL RESOURCE SYSTEMS ANALYSIS

SELECTED PAPERS ON SOIL DEGRADATION PROBLEMS
AND SOIL CONSERVATION TECHNIQUES AND MANAGEMENT:
USE AND IMPLEMENTATION IN AFRICA

To accompany Handbook on soil degradation problems
and soil conservation techniques and management;
Use and Implementation in Africa

RESOURCE HANDBOOK SERIES NO. 1

Volume 2

Clark University
International Development Program
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Binghamton, NY 13902

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Cooperative Agreement on Human Settlement and Natural Resource Analysis and Management, United States Agency for International Development

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USAID Grant Number DAN-1135-A-00-1078-00

1983

...much of the technical knowledge required for erosion control has been available for fifty years. While there is scope for increased understanding, the major challenge is now the development of conservation measures and strategies which conform to the economic, social, and political realities of the countries where they are needed.

Rorke B. Bryan, 1979

Humans are out of perceived necessity destroying the basis of their own livelihood as they violate the limits of natural systems. Those most vulnerable to these trends are the poor of the world. Their search for the basic requirements of food and fuel often force them to hasten the destruction of their own environment.

World Bank Forestry Sector Paper, 1978

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CURRENT RESEARCH:

Elwell, H.A. 1981. A soil loss estimation technique for southern Africa. In Soil conservation: Problems and prospects, ed. R.P.C. Morgan. Chichester: John Wiley and Sons.

Food and Agriculture Organization of the United Nations (FAO). 1979. Soil and water conservation. In Watershed development with special reference to soil and water conservation. FAO Soils Bulletin no. 44. Rome: FAO.

Food and Agriculture Organization of the United Nations (FAO). 1965. Types of erosion damage. In Soil erosion by water: Some measures for its control on cultivated lands. Rome: FAO.

El-Swaify, S.A., E.W. Dangler and C. L. Armstrong. 1979. Predictability parameters for rainfall erosion in the tropics. In Soil erosion by water in the tropics: A state of the art. Washington, D.C.: United States Agency for International Development.

El-Swaify, S.A., E.W. Dangler and C.L. Armstrong. 1979. Erosion control measures. In Soil erosion by water in the tropics: A state of the art. Washington, D.C.: United States Agency for International Development.

El-Swaify, S.A., E.W. Dangler and C.L. Armstrong. 1979. Literature cited. In Soil erosion by water in the tropics: A state of the art. Washington, D.C.: United States Agency for International Development.

Lal, R. 1979. Physical characteristics of soils of the tropics: Determination and management. In Soil physical properties and crop protection in the tropics, ed. R. Lal and D.J. Greenland. Chichester: John Wiley and Sons.

Wischmeier, W.H. 1976. Use and misuse of the universal soil loss equation. Journal of Soil and Water Conservation 31:5-9.

Roose, E.J. 1977. Use of the universal soil loss equation to predict erosion in West Africa. In Soil erosion: Prediction and control. Soil Conservation Society of America, Special Publication no. 21. Ankeny, Iowa.

Skidmore, E.L. 1977. Criteria for assessing wind erosion. FAO Soils Bulletin 34:52-62.

Fournier, F. 1967. Research on soil erosion and soil conservation in Africa. Sols Africains 12-53-96.

COLONIAL EXPERIENCE:

Stockdale, F. 1937. Soil erosion in the colonial empire. Empire Journal of Experimental Agriculture 5(20):282-297.

Hellen, J.A. 1969. Colonial administrative policies and agricultural patterns in tropical Africa. In Environment and land use in Africa, ed. M.F. Thomas and G.W. Whittington. London: Methuen and Co.

Hailey, Lord (GCSI, GCIE). 1945. An African survey. London: Oxford University Press.

Sudan, Government of. 1944. The report of the Soil Conservation Committee, Sudan Government. Khartoum: McCorquodale and Co.

Young, R., and H. Fosbrooke. 1960. Smoke in the hills: Land and politics among the Luguru of Tanganyika. London: Routledge and Kegan Paul.

INDIGENOUS METHODS:

Berry, L., and J. Townshend. 1972. Soil conservation policies in the semi-arid regions of Tanzania: A historical perspective. Geografiska Annaler 54(9A, 3-4): 241-53.

Stocking, M.A. 1978. Relationship of agricultural history and settlement to severe soil erosion in Rhodesia. Zambezia 6(2): 129-45.

Mbithi, P.M. and D. Kayongo-Male. 1978. Local environmental perception and soil and water conservation practices. In Soil and water conservation in Kenya. Occasional paper no. 27. Nairobi: Institute for Development Studies and Faculty of Agriculture, University of Nairobi.

Hartley, B.J. 1938. An indigenous system of soil protection. East African Agricultural Journal 4:63-6.

Okigbo, B.N. 1977. Farming systems and soil erosion in West Africa. In Soil conservation and management systems in the humid tropics, ed. D.J. Greenland and R. Lal. Chichester: John Wiley and Sons.

RE-EVALUATION OF INDIGENOUS METHODS:

Okigbo, B.N., and D.J. Greenland. 1976. Intercropping systems in tropical Africa. In Multiple cropping, ed. R.I. Papendick, et al. American Society of Agriculture, Special Publication no. 27. Madison, WI: ASA.

Fauck, R. 1977. Soil erosion in the Sahelian zone of Africa: Its control and its effect on agricultural production. In Proceedings of an International Symposium on Rainfed Agriculture in Semi-arid Regions, ed. G.H. Cannel. University of California and Oregon State University, April 17-22.

Dunne, T. 1977. Studying patterns of soil erosion in Kenya. FAO Soils Bulletin 33:109-22.

Phillips, R.E., et al. 1980. No-tillage agriculture. Science 208:1108-13.

CURRENT RESEARCH

Elwell, H.A. 1981. A soil loss estimation technique for southern Africa. In Soil conservation: Problems and prospects, ed. R.P.C. Morgan. Chichester: John Wiley and Sons.

1. Introduction

A new approach to soil loss estimation has been proposed for Southern Africa (Elwell, 1978a). It is based on modelling principles whereby the 'real world' system is simplified to provide a means of predicting the consequences of various management decisions. The purpose of a soil loss estimation is to bring together all sources of information into a formal arrangement which represents the best advice available. Established theory, expert opinion, laboratory test data and results of field-plot measurements are all valid data sources. Useful information is provided at all stages of model building and, because of low development costs, a variety of models can be constructed to suit specific purposes and localities.

The modelling approach is considered to be suited particularly to countries unable to support expensive research programmes but which urgently require a decision-making aid to combat soil erosion. One such model, coded SLEMSA (Soil Loss Estimator for Southern Africa), which has been designed to predict mean annual soil loss arising from sheet erosion on the area of arable land between two adjacent contour ridges, has attracted wide international interest. In November 1976 it was developed into a design procedure intended to give a 'first estimate' of soil losses in Southern Africa (Natal Agricultural Research Bulletin No 7, 1976). At the 1978 meeting of the Southern Africa Regional Conference for Conservation and Utilisation of the Soil (SARCCUS), Lesotho, Botswana, Swaziland, Malaŵi, Zimbabwe-Rhodesia and South Africa agreed to take part in a co-ordinated programme of research based on SLEMSA. More recently, a simple but effective graphical design procedure has been

drawn up for ZimbabweRhodesia (Elwell, 1979).

The purpose of this paper is to summarise the main features of the construction and application of the SLEMSA model and to briefly describe recent developments towards providing the necessary back-up instrumentation and techniques.

2. Data Types and Sources

The information employed in model building and testing is called 'fundamental' data. Before the model can be applied in practice, the designer must be provided with a body of data from which he can select the values of certain site variables. This is called 'user' data. Confusion can be avoided if this distinction is clearly understood.

Most of the locally based fundamental data originated from the work of N W Hudson (Hudson 1965 Elwell 1971). The principal submodel, K, was built up from a limited amount of bare plot data, supplemented by the experience of members of the Natal multidisciplinary team. The C submodel was developed from measurements taken on local grazing trials (Elwell and Stocking 1974). The topographic submodel, X, was modified in part from the slope factor relationship of the Universal Soil Loss Equation (Wischmeier and Smith 1965). Significant progress has been made towards building up a local user data bank (Elwell 1978b).

3. Model Building

3.1 Approach A schematic diagram of the model is shown in Figure 1. In the first stage, the soil-erosion environment is divided into its four physical systems: climate, soil, crop and topography. Each system is thereafter treated as a separate entity. For instance, any practice having an influence on soil properties, such as tillage or management, is accounted for within the soil system; and any factor related to the crop is dealt with within the crop system. The approach differs in concept from the Universal Soil Loss Equation (Wischmeier and Smith, 1978) where tillage and cropping are both part of the cropping management factor, C.

Although at face value this may appear to be a minor conceptual difference, nevertheless it has important theoretical and practical implications. The major control variables can now be identified and quantified, thus introducing an interpolative capability which

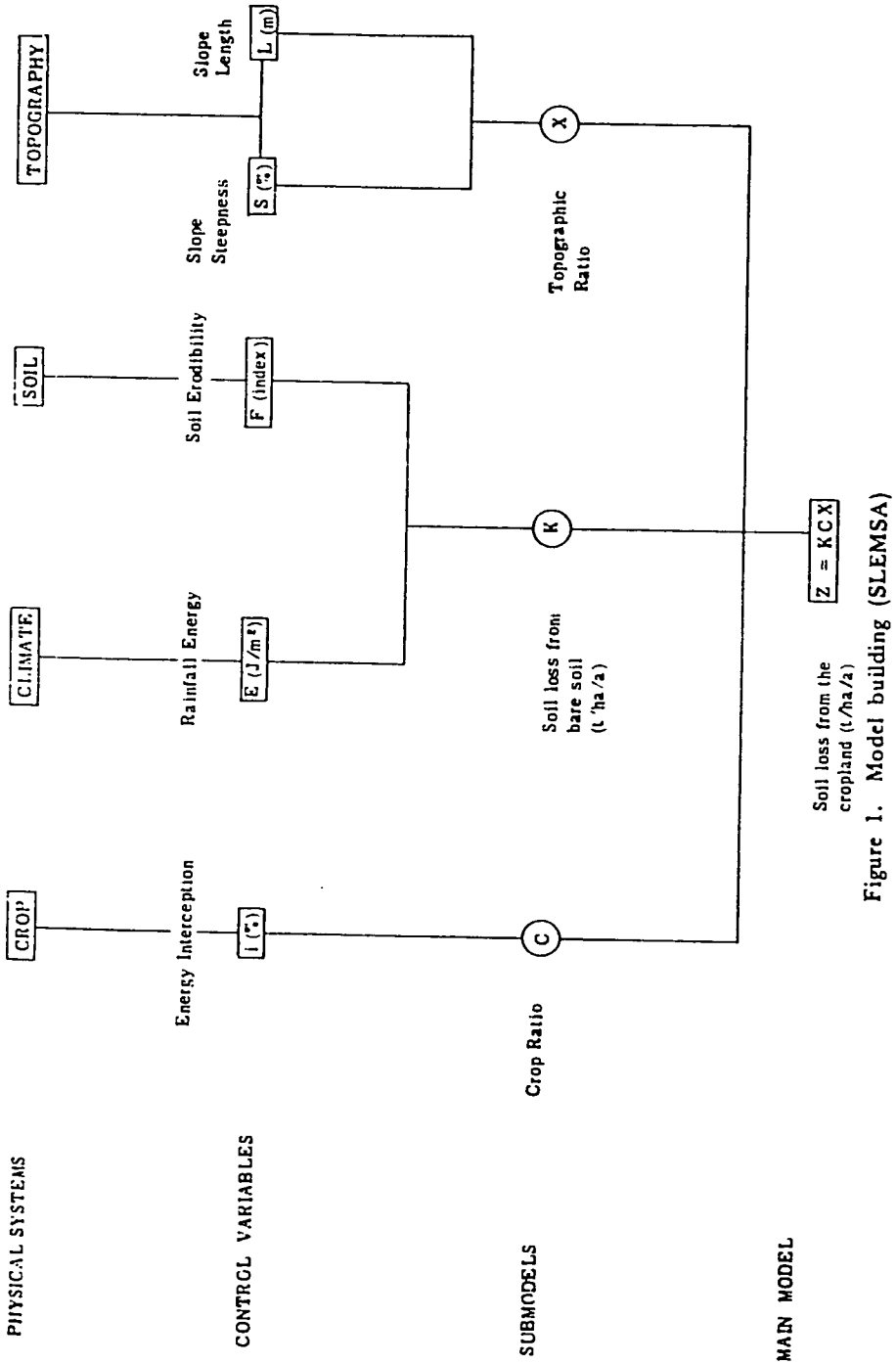


Figure 1. Model building (SLEMSA)

considerably reduces the number of field-plot measurements required.

The control variables are the major over-riding factors determining soil losses within each of the four systems. Five control variables have been identified for estimating sheet erosion losses from arable lands. These are seasonal rainfall energy (E); the amount of rainfall energy intercepted by the vegetation (i); the soil erodibility (F); slope length (L) and slope percentage (S).

Ideally the control variables should be easily measurable and rational. Rationale is particularly important because it leads to logical explanations which facilitate understanding and progress. For example, rainfall energy offers a logical explanation of soil erosion as a work process, and this has led to the concept of quantifying the role of crops in terms of the amount of rainfall energy intercepted by the ground cover.

The control variables are expressed in terms of soil loss at the level of the submodels. The principal submodel, K, combines the influences of mean seasonal energy E and soil erodibility to give an estimate of the mean annual soil loss from conventionally tilled bare soil at 4.5% slopes, 30 m long. C is a ratio which corrects the soil loss from bare fallow to that for the crop grown; and X is a ratio which adjusts for changes of slope steepness and length. The submodels developed for the Zimbabwe-Rhodesia highveld are shown in Figures 2 - 5. The submodels interact as simple products in the main model to give an estimate of the mean annual soil loss from a specific crop type, climate, soil type, slope steepness and slope length.

3.2 Validation. SLEMSA was built to have a predictive capability on the Zimbabwe-Rhodesian highveld. It was tested against field experience as a learning tool and as a predictor of soil losses from research plots.

Senior field men have confirmed that its predictions match their experience and there have been many instances where application of the model has improved understanding. For instance, the high rate of soil loss observed from cotton lands, previously attributed entirely to the poor ground cover provided by the crop, was shown to be caused mainly by substandard crop management and soil treatment. When tested as an estimator of soil erosion from field plots, SLEMSA predicted mean annual losses to within 1.7, 2.6, and 4.3 t/ha/y with 50%, 70% and 90% confidence respectively. Considering, therefore, its early stage of development, it shows great promise as a predictive tool.

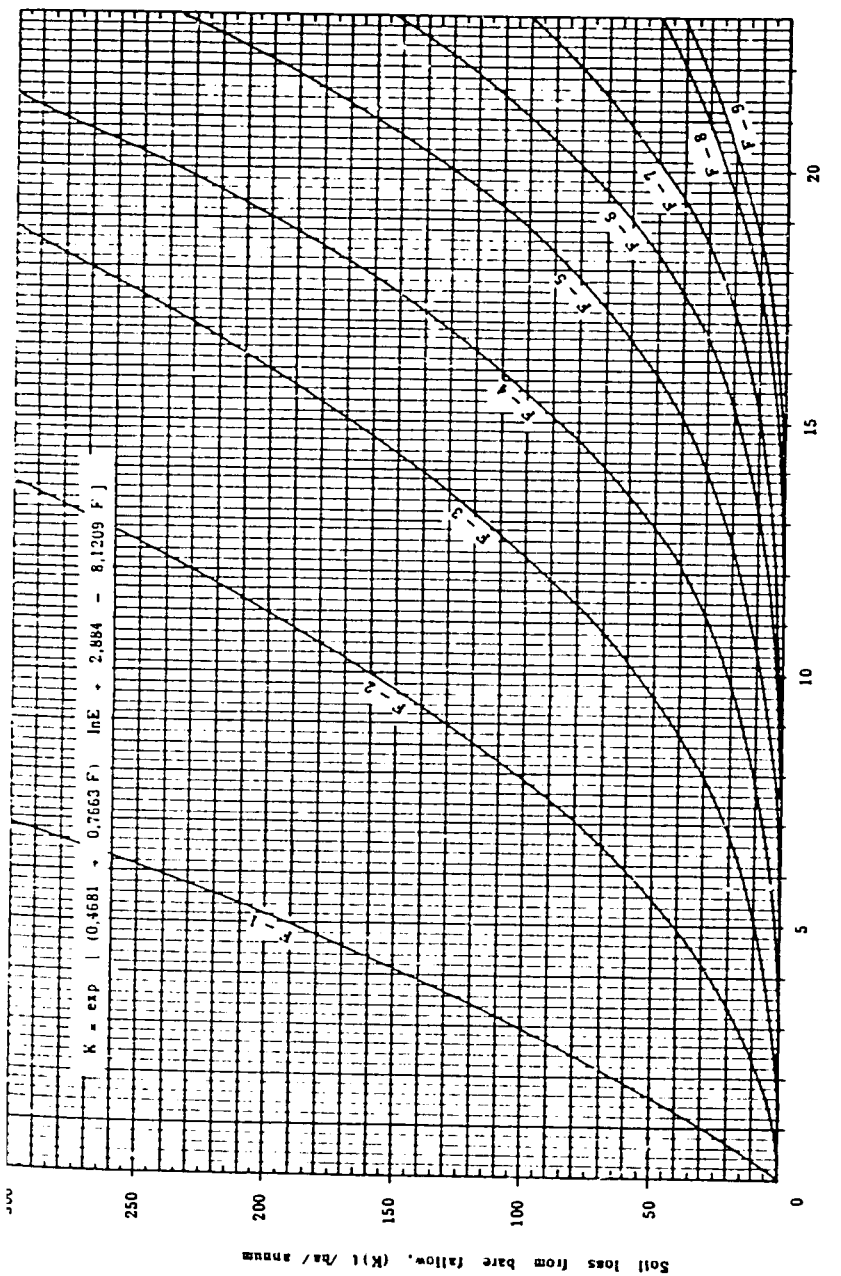
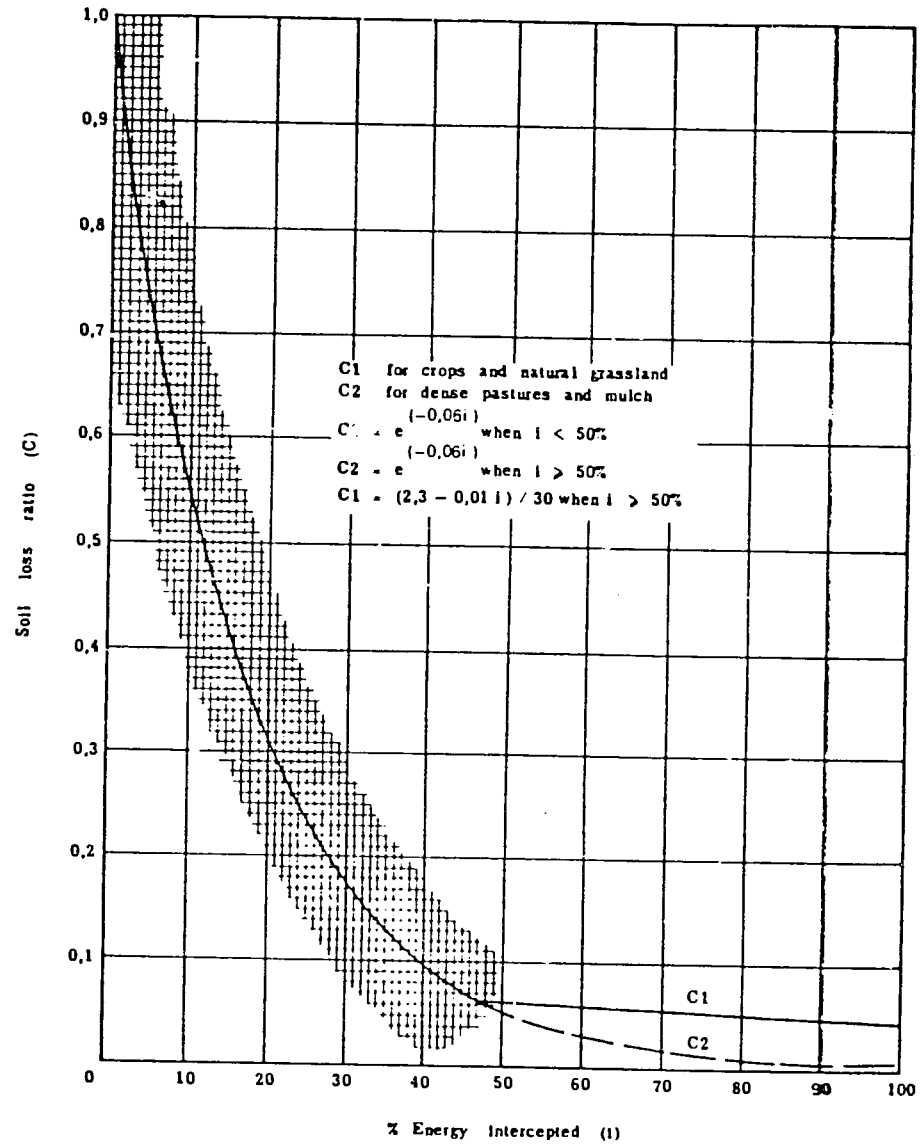


Figure 2. Relationships between K, E and soil erodibility F.



C1	1,0	0,55	0,30	0,17	0,09	0,060	0,057	0,053	0,050	0,047	0,043
C2						0,050	0,029	0,015	0,008	0,005	0,002

Figure 3. Crop cover model

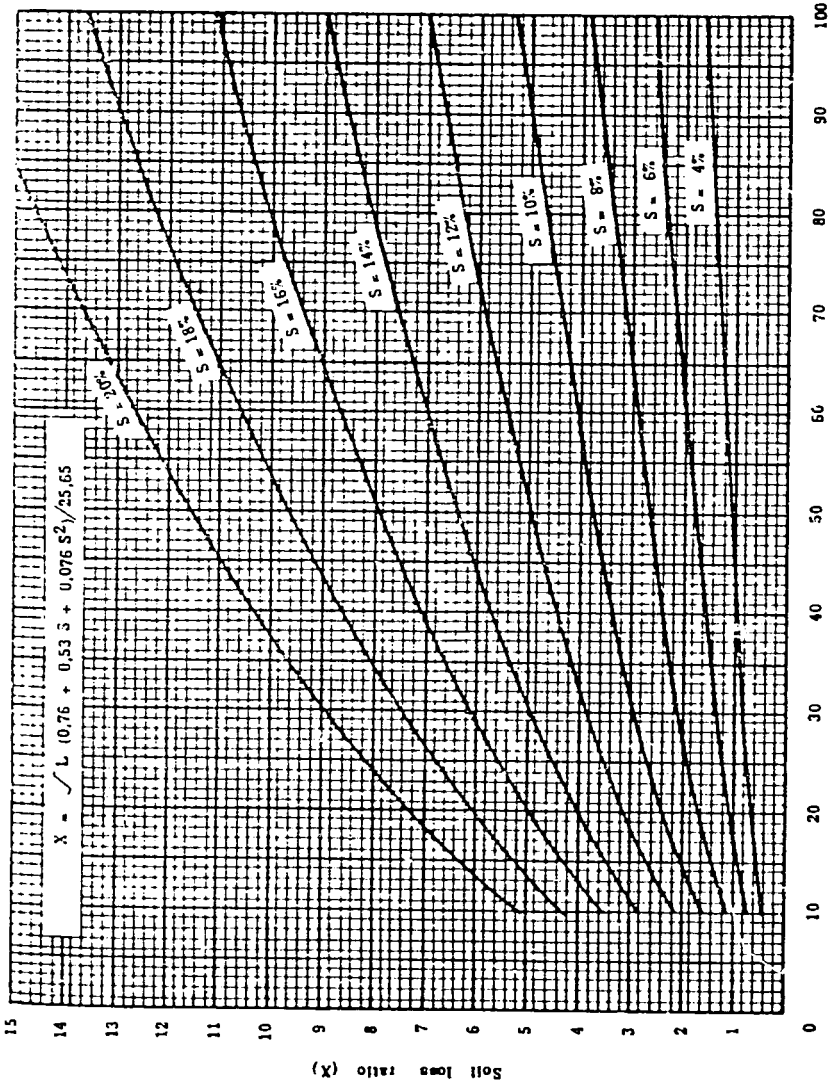


Figure 4. Topographic model for S > 4%

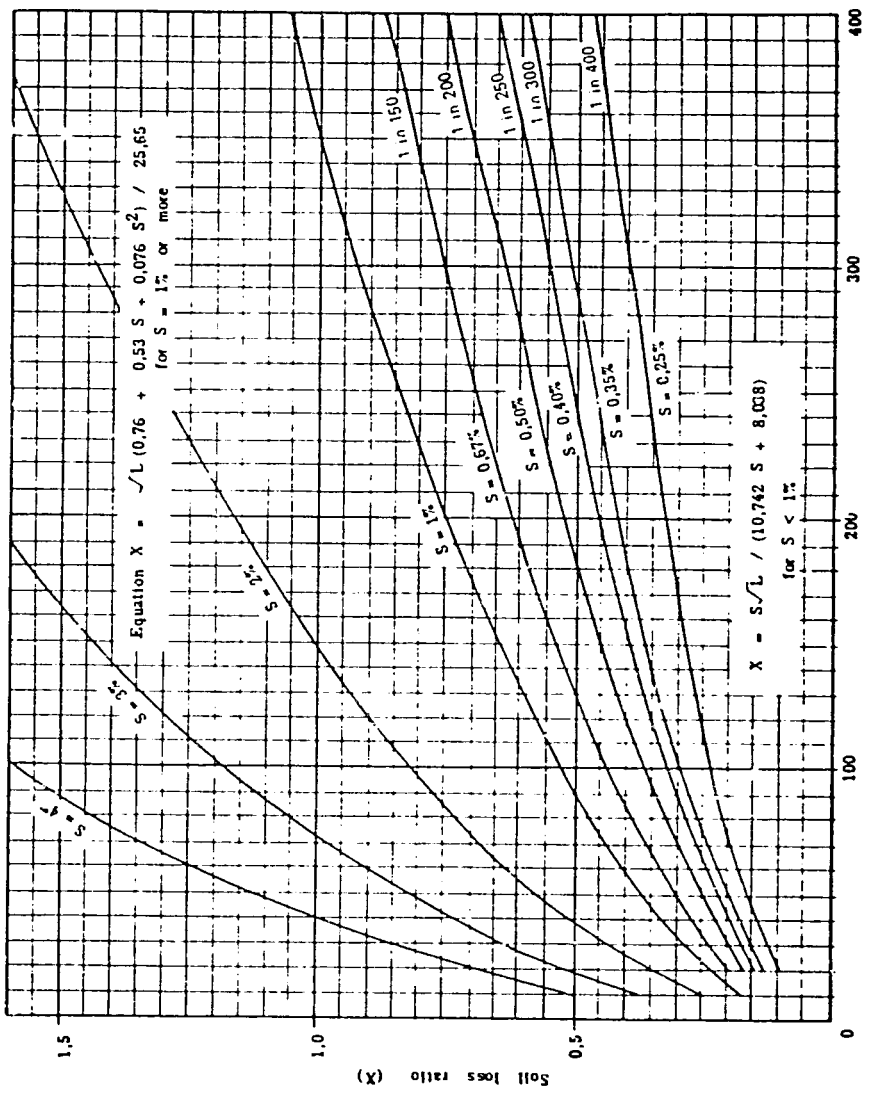


Figure 5. Topographic model for S < 4%

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3.3 Advantages and Limitations. The modelling approach to soil loss estimation offers considerable advantages over existing techniques. Useful data can be obtained at all stages of model building at relatively low cost and in less time than for conventional methods. Comparative models, developed from unsophisticated data bases, merely formalise accumulated field experience; whereas more sophisticated models designed to give absolute values, can be developed from the results of a relatively few carefully selected field plots. Once the mathematical relationships have been established, soil losses can be predicted for other field conditions provided only that the relevant values of the control variables are known. Because of these advantages a variety of models can be formulated to suit different localities and field conditions or for specific purposes. Modelling techniques can also be supplied to assist in generating the necessary user data. Such methods are particularly valuable in the case of crop cover (Elwell, 1978b). The limitations of models must, however, be clearly understood.

The current SLEMSA submodels were developed and tested on the Zimbabwe-Rhodesian highveld. Although some small progress has been made towards rationale, they remain essentially empirical and cannot be used with any certainty outside the area for which they have been validated. Furthermore, the Estimator is by no means fully developed as a predictor of highveld soil losses. Consequently plans are in hand to improve the accuracy of the model for the highveld and, through SARCCUS, to test its capability throughout Southern Africa. This will inevitably lead to the development of a greater variety of submodels each suited to a particular range of field conditions.

Because of its simplified nature, the Estimator cannot take into account all the complex interactions involved in the soil erosion processes. Some interactions are accounted for within the submodels themselves but not between submodels. At the moment there is no evidence that this weakness will produce major errors but should these arise they will be revealed during validation.

4. Design Procedure

The objective of the SLEMSA model is to reduce sheet erosion losses from contour ridged land to acceptable levels by modifying the length of slope, slope percentage, tillage treatments, cropping practices and management standards. The Zimbabwe-Rhodesian design procedure (Elwell 1979) consists of the submodels shown in

graphical format identical to Figures 2 to 5 and a series of user data tables from which the values of the control variables are selected for a particular site. The designer begins his task by estimating the mean annual soil loss from a farmer's existing rotation and comparing it to a predetermined target level. If the losses exceed the target figure, the designer will suggest modifications to bring the soil losses down to acceptable levels. This may involve major alterations or merely adjustments to such details as planting dates or the number of times a soil is disced after ploughing. However the contribution to soil loss of even minor adjustments can be anticipated from the relative change in the value of the control variables. The method is therefore simple to use, flexible and instructive.

5. Instruments and Techniques

Significant progress is being made in the current research programme towards further reducing the time and costs of developing models.

5.1 Developing and Testing Models. Recent experiments show that one plot-year of data can contribute towards validation, provided that the values of the control variables are carefully monitored on the experimental site. Furthermore a complete F line in the K submodel (Fig 2) can be drawn up by plotting the cumulative energy and and soil loss for a single year of above-average rainfall. These two developments lead to a significant reduction in the number of plots now required to build and validate new models.

Tests are being undertaken to investigate the potential of simulation techniques for developing and validating submodels. At the time of writing some encouraging progress is being made towards reproducing the SLEMSA Submodel C in the laboratory.

5.2 Soil Erodibility. The development of a satisfactory quantitative measure of soil erodibility has been given a high priority in the research programme. A small mobile rainfall simulator has been built to assess the 'basic' erodibility (Fb) of soils *in situ*. Soils will be judged according to the amount of soil loss collected during application of a standard storm of 750 Joules.

The influence of management (Fm) is being quantified in terms of changes in the physical properties of the plough layer. Parameters so far identified as important are surface ponding, clod-size distributions and bulk density.

Food and Agriculture Organization of the United Nations (FAO). 1979. Soil and water conservation. In, Watershed development with special reference to soil and water conservation. FAO Soils Bulletin no. 44. Rome: FAO.

7. SOIL AND WATER CONSERVATION

7.1 GENERAL

The scope of soil conservation is very wide and encompasses much more than mere physical works for erosion control. It comprises in fact a comprehensive approach to soil, water and farm management, in which all physical soil conservation practices contribute only partly towards the overall targets of improving and maintaining soil fertility, soil-water-plant relationships, and through these the attainment of sustained high crop yields.

Soil is a natural resource of a country. As such its conservation should be a national responsibility. In the past insufficient attention was paid to this important aspect in most developing countries. More recently however these countries have become aware that their agricultural resources are dwindling as a result of soil degradation. Governments and farmers are now making efforts to restore and improve their soils in the interests of the nation as well as individual farmers.

It is beyond the physical and economic capacity of rural populations to bear the burden where large investments are required to repair the damage caused by the misuse of natural resources over many generations. But improvements carried out in the upper parts of a watershed benefit the lower parts, and the whole river basin with its rural and urban population, towns and industries as well. Consequently, all sectors of the population should contribute their share to the reclamation of the rural parts of a watershed (which generally contain poor subsistence farmers).

The nature of the agro-ecological zone has a very decisive influence on land use, socio-economic conditions and constraints and on the soil and water conservation practices to be applied within a watershed development plan.

No ready prescriptions can be made for all possible situations and conditions that will be encountered throughout the world. However, one statement can be made which holds good under all conditions, wherever soil erosion and land degradation are reduced or prevented by adequate soil conservation measures, water will also be conserved, and the ecological balance between man and nature will be improved.

Erosion has been mentioned as a major factor in land suitability classification. Soil conservation practices are often the major components which make improved land use possible.

This publication is not a soil conservation handbook. However an attempt is made to supply information necessary for the important practices which should be applied in the framework of a comprehensive watershed development plan.

The various soil conservation practices are discussed under the following headings, according to the major Soil Utilization Group.

(i) Soil conservation practices on crop land

(ii) Soil conservation practices on pasture and range land

(iii) Soil conservation practices on forest land

(iv) Soil conservation practices on waste land

7.2 CONSTRAINTS

7.2.1 General

Soil conservation deals with all lands within the boundaries of a drainage basin. It is not only concerned with the agricultural lands under cultivation but also with forest, range lands, areas destroyed by erosion, and others that can serve as protection areas only. Furthermore, in comprehensive watershed development, special attention must be given to climate, hydrology and the ecological balance of a given watershed.

A very close and interdependant relationship exists between all phases of comprehensive watershed development. Soil conservation measures on agricultural lands alone can only be partly effective. It is however a major component and an important tool for improvements and of direct benefit to the farming population. Protecting and preserving the limited resources of arable land certainly deserves special attention. However, without the complementary works in other sections of a watershed development plan such treatment may sometimes only give temporary relief. For example, the hydrology of a watershed depends on the conditions of all its lands.

The agricultural sector probably may be only a minor factor in the overall water regime of a drainage area. This is particularly important where climatic conditions are such that irrigation is required for full production, and irrigation water has to be supplied from local sources. The same applies to the drainage conditions of the bottom lands which are in most cases the areas of highest production. Hereditary laws and fragmentation of the land may sometimes prevent any physical work for the conservation of the small and scattered plots of individual farmers and whole communities. The selection of soil conservation measures depends to a large degree on land consolidation, cooperation between farmers and on other aspects which may be different in each locality. It is important to investigate and fully comprehend these prerequisites to prevent a patchwork approach which would lead to certain failure.

7.2.2 Human Behaviour

The human element is probably the most serious limiting factor in carrying out improvements on agricultural lands. Pressure on the land by a rapidly increasing rural population has been the cause for most of man's destructive activities. The need to produce more and the constantly decreasing cultivated area per household have caused the conversion of marginal areas into cultivated fields. The result is accelerated erosion on steep hillsides, which should not have been cultivated at all. Many of the present badlands were in the past such areas.

There are many aspects of human behaviour which may influence the reaction of farming communities toward the requirements of proper soil conservation activities in a watershed, such as customs, traditional constraints, social organization within the family and the village, and others. All this has to be considered in carrying out soil and water conservation within the framework of comprehensive watershed development. It would be futile to embark on these activities without the full cooperation of the farming communities and the individual farmers.

The need for more food and clothing (milk, meat, wool) has caused the deterioration of range and pasture lands through overgrazing.

The increased demands for fuel and building material, together with shifting cultivation, have destroyed large areas formerly well protected by forest.

7.2.3 Shifting Cultivation

Shifting cultivation has been practised over many generations and is only well adjusted to a sparse, sometimes semi-nomadic population. Even improved systems such as "Taungya" cultivation, have lost their value due to the ever shorter cycle between cultivation and forest. In some countries efforts are still made to introduce improvements to the system which may give some temporary relief from increasing soil erosion. It seems however that the time has come to abandon any hope that permanent solutions can be found in a system which worked well 100 years ago but is not adjustable to the changed circumstances of today. Watershed management is supposed to give long-term solutions. Consequently, it is suggested that shifting cultivation be excluded from comprehensive watershed development as a method of soil conservation, except in very special cases of sufficient land reserves of high capabilities. Reclamation of land under shifting cultivation and conversion into permanent cropland is discussed in Chapter 8.

7.2.4 Land Fragmentation

Fragmentation of land is a serious problem. It is especially so on irrigated land where efficient water distribution and good drainage are prerequisites for the expected increases in yields through irrigation.

Individual farmers may have a number of small parcels scattered over a large area which makes good farm management practices difficult. Irrigation water is diverted from one field into another and so is true drainage water. A lack of access roads makes all farm work extremely difficult and cultivation with even smaller mechanical implements practically impossible.

Soil conservation practices have to be applied irrespective of the irregular boundaries of the small plots of individual farmers.

On uniform level lowlands consolidation may be relatively easy to accomplish. On sloping uplands, often intersected by uncultivable plots and with changing slopes, individual plots may be scattered over large areas and have a wide variation of use suitability.

Land consolidation under such conditions is difficult. The minimum requirement for such areas would be an agreement between farmers to carry out soil conservation improvements without regard to the boundaries of the individual owners. This is a difficult undertaking and should be considered as a temporary solution only.

If more intensive land use and other improvements are envisaged especially those with high investment costs, such as irrigation, drainage, land reclamation, then land consolidation is the final prerequisite for such activites. This has to be spelled out in very clear and definite terms to the relevant authorities and to the farmers.

7.3 SOIL CONSERVATION ON CROPLAND

Distinctions have to be made for soil conservation activities on low and level lands with slopes up to 2% (code L) and on uplands with slopes from 2-25% (code U), sometimes even more than 25-55% (code UV). Furthermore, soil conservation practices for annual, perennial and tree crops are different.

It has been pointed out that good soil management is the first and foremost step in soil conservation on agricultural land. This implies that only land which can be properly managed should be under cultivation. An exact land use suitability survey is consequently the basis for any decision in regard to agricultural lands which are at present cultivated but should be retired, or lands which are used for other purposes but could be converted to arable land, and the soil conservation measures to be applied on all cultivated lands.

7.3.1 Lowlands

Lowlands are the alluvial plains and the bottomlands of the small tributaries in a watershed. In most developing countries they are used mainly for the production of the staple food crops. Soil conservation works in these areas are of a different nature to those on uplands. Erosion control practices are necessary only in limited areas.

The water regime, land use and crop production depends to a large extent on the condition of the upper parts of the watershed and the soil conservation works carried out on all uplands cultivated and not cultivated. Under climatic conditions which require supplementary irrigation, the water supply from local sources depends on the condition of the drainage basin. Consequently the cropping patterns on lowlands may undergo marked changes with the change of conditions in the watershed, whether soil degradation and misue, or its improvement.

Water storage, prevention of flash floods and sedimentation in the drainage system, recharge or groundwater resources, springs, riverflow and many other benefits which would normally serve the lowland farmers, would be the results of integrated watershed development - conservation of the natural resources of the drainage basin.

It would be unwise to start soil conservation activities on the lowlands without having done so first on the uplands. This is a simple fact, easy to understand. It is surprising that it is still so often disregarded.

The main soil and water conservation practices on lowlands are concerned with maintaining and improving soil fertility by good farm management. This includes - in the case of irrigation - proper levelling and application of water, prevention of alkalinity and creation of waterlogging.

Under dry-land farming the main objective should be good soil, water and farm management.

There may be need for improvements or for the repair of damage already done. This may include surface and subsurface drainage, interception and diversion ditches, river training and others. All these works would be effective if proper watershed development had been implemented on the uplands. Otherwise there would be a return in a short time to the conditions as they were before implementation of the works. As on uplands, land consolidation and prevention of new fragmentation, and cooperation between individuals and villages, are indispensable for planning, implementation and maintenance.

River training, construction of small dams, weirs, infiltration galleries, and other improvements for irrigation, such as land levelling, are discussed in Chapter 8. In this section surface drainage and water conservation for dryland farming is explained, these being the major soil conservation practices for such lands.

7.3.2 Systems of Surface Drainage on Flat Land

The guiding principle in Surface Drainage, in contrast to that of Erosion Control, is that on flat land (up to 1-2% slope) the cultivation rows are oriented in the direction of greatest slope, in order to drain off surplus water as fast as possible.

i. Cross ditch system

Direction of cultivation. The rows are laid out on the greatest slope, at right angles to the contour lines. The basic tillage operations (normal and deep ploughing, cultivating, etc.) are also done in this direction, whilst disking, rolling and smoothing are done at right angles or diagonally. Seeding however must be done on the greatest slope.

The field ditches towards which surplus water drains from the rows, are oriented at right angles to the rows, slightly off the contour so as to obtain a small but continuous gradient, generally 0.3-0.5 percent

- The spacing between ditches should not exceed 200 metres on slowly permeable soils, nor 100 metres - or even less - on very slowly permeable soils.
- The draining length of the ditches should not exceed 500 metres.
- The ditch section should have a depth of 30 cm with 1:8 side slopes.
- The ditch makes up part of the field and should be cultivated and sown like the rest of the field.
- The ditches are crossed with all implements. Ploughs are lifted before crossing.
- Ploughing of the ditch is done along its length, and this operation is used to renew the cross section since sediment and cultivations tend to fill it in.
- Seed drills cross the ditches without the sowing being interrupted.

It is most important that the furrows of seeding and tillage machines should enter the ditches so as to avoid obstructions in the flow of drainage water into them.

The collecting ditches into which the field ditches drain, are placed parallel to the rows and in the direction of greatest slope.

- The cross section of the collecting ditch is designed according to the runoff expected. The bottom should be 30 cm lower than the field ditch, and the side slopes - if the ditch is not to be crossed by machinery - 1:4.

- The distance between collecting ditches depends on the draining length of the field ditches.

- The collecting ditch should have a plant cover whether this be natural or planted. The cross-section is usually that of a waterway and the maintenance should be similar. Special regard should be paid to mowing the vegetation, otherwise it will obstruct the flow of drainage water and may cause silting up of the ditch. On very small slopes and with a stable soil structure, this ditch may also be cultivated and sown.

- The outlet from the field ditch into the collecting ditch should be protected against erosion by stonework or vegetation.

- The collecting ditch drains into a natural drainage way or into a main ditch.

ii. Bedding System

This system is adapted to - rapid draining of surface water, or draining excess water present in the topsoil because of an impermeable subsoil or both cases together.

In principle the system is similar to the cross ditch system but the distances between the field ditches is less and raised beds are constructed on the whole field. Drainage water is carried away by a deep furrow opened between two beds.

- The beds are laid out along the greatest slope, preferably on the basis of a topographic map, which need not, however, be very accurate.

- The bedding width is determined by the nature of the soil, its permeability, the slope and the kind of cropping, and is generally 15-30 metres. On slowly permeable soils with little slope, the beds are even narrower. With row-crops the width is a multiple of the row width, and in every case the bedding width is a multiple of the main implements.

- The height difference between the crest of the bed and the open (draining) furrow is about 30-40 cm. When the beds are of 30 metres width this height difference creates a slope of 2-3% (from the crest to the furrows).

- The distance between collecting ditches is determined by the quantity of surface runoff.

Construction. The beds are formed with a mouldboard or disk plough, turning the furrows towards the crest of the beds. The job may be done in one operation, or over a period, by ploughing the same "lands" in the same direction every time.

- Prior to ploughing, the strip where the open furrow is located is levelled and checked.

- The collecting ditches are excavated before the beds are formed and the spoil is used for filling in large depressions.

Cultivating the field. Ploughing is always done along the beds, since otherwise the drainage furrows could not function properly. Other tillage such as disking, cultivating, rolling etc. may be done across the beds.

- When ploughing is completed the (draining) furrow should be checked to ensure that it is deep and free of obstructions. If other tillage operations are done, they should be followed up by a ridging plough opening up the furrow. A furrow that is not deep enough or free of obstructions will wet, instead of drain, the area and make matters worse.

- The field ditches are cultivated as part of the field with the exception of the ploughing which is done along the ditch length. When a field ditch occurs on the field boundary, a strip of sufficient width, to enable farm implements to turn around, should be left between the ditch and the boundary. When implements turn round before the ditch, free drainage from the furrows is obstructed, whilst turning in the ditch itself blocks it up.

- The collecting ditches may be vegetated or tilled according to the stability of the soil and the slope of the field. These ditches drain towards natural drainage ways or to main ditches.

- The collecting ditches may be dispensed with if the field ditches can drain into natural drainage ways close enough to the field.

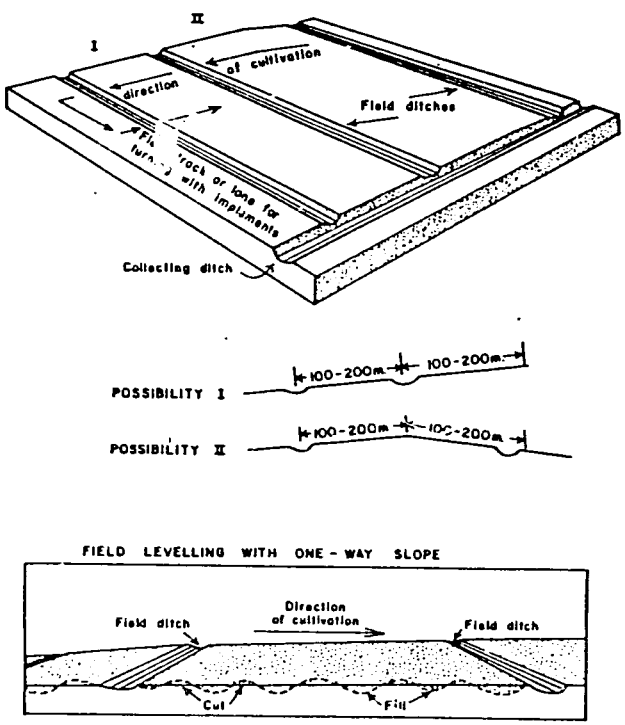


Figure 1. SYSTEMS OF SURFACE DRAINAGE ON LEVEL - LOWLAND

Bedding can also be combined with the cross-ditch system (possibility II in Figure 1). This makes cultivation of wider strips of land possible. It should be done especially on very level land with low permeability On such lands field levelling on one way slopes may also be advantageous (Fig.1).

7.3.3 Water Conservation on Level and Lowland (0-2%)

In semi-arid zones water conservation during short or low rainfall seasons is of major importance for crop production

The runoff rate on level and gently undulating lands with slopes of up to 2% is generally relatively low. However, in these semi-arid zones rainfall intensities are very often extremely high. This may cause serious sheet and rill erosion through heavy runoff during the short cloud bursts.

All efforts should be made to retain as much moisture as possible both for crops grown during the rainy season and after the rainy season. Stubble mulching and contour cultivation are two practices suitable for this purpose.

i. Stubble mulching

Stubble mulching is best applied on fairly level land and where wind erosion is also a serious hazard. The land is not turned over by conventional ploughing but cultivated with a chisel plough a subsoiler or "duck foot" cultivator, which leaves all the stubble of the former crop on the surface, but opens up the soil so as to facilitate the maximum possible water infiltration and retention.

ii. Contour cultivation

Contouring is a basic practice which is fundamental to many other practices (terracing, strip-cropping, bench terracing, etc.). Contouring reduces water erosion due to the increased infiltration of water in the cultivation furrows and to the checking of surface flow by the furrows.

Use and effectiveness. The method is effective on slopes up to 2% but where there are many gullies, or infiltration and permeability are slow, then contouring alone does not provide sufficient protection even on such gentle slopes.

Marking out is done by two people. A simple way of doing it is described and illustrated in Figure 2. One person (A) has a hand-level, the other (B) has a rod or staff whose height equals the eye-level of (A), some means of marking (stakes or powdered limestone), and a hammer. The first line is marked at the upper part of the field, starting from the field boundary, a track or a gully. (A) marks the first point of the line with a stake, while (B) walks - as nearly on the contour as he can estimate - about 20 metres. (A) looks through the hand-level and directs (B) up-slope or down-slope until the cross-wire intersects the top of the rod which (B) holds upright. This point is then marked out after the third or fourth point has been marked in this way, (B) remains at this point whilst (A) advances, overtakes (B), and positions himself 20-25 metres beyond him on the contour. This point likewise is marked and then (B) advances as before 3 or 4 points and the process is repeated.

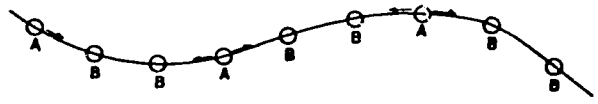


Figure 2. MARKING OUT A CONTOUR

Distance between the contour lines

Up to 2% - 50 metres

Over 2% - 30-40 metres

Forming the ridge. After the marking out is completed a few furrows are ploughed around the marked lines, forming a ridge which marks out the field for subsequent ploughing and also serves to reduce surface runoff. In order to build a firm ridge which can not be easily obliterated it should be constructed with 2 or 3 passes of the plough.

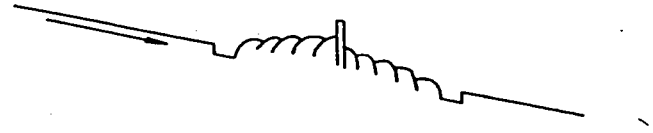


Figure 3. FORMING THE RIDGE

Tillage is usually done between two ridges, this area being considered a ploughing "land". (Figure 4). When ploughing the field, attention should be paid to raising and strengthening the ridges by ploughing them twice, if necessary

In contour cultivation there arises the problem of "point" rows due to the varying distances between contour lines. In gathering around the ridges, as the ploughed strips approach each other as ploughing proceeds a uniform width of strip is left which is wide enough for the implement to turn on. This strip is ploughed last in the manner indicated in Figure 4.

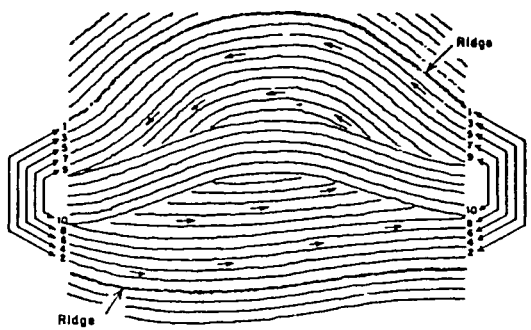


Figure 4. PLOUGHING BETWEEN RIDGES

7.3.4 Uplands

A major distinction should be made between uplands and lowlands. Upland soils are derived in most cases from the parent rock and very often are of medium to light texture. They generally have an undulating to steep topography. They are exposed to all kinds of water erosion and to the abrasive and selective forces of winds. There is a constant downhill movement of soil particles. Internal and surface drainage is generally good and waterlogging occurs only under specific circumstances. Airdrainage is good and soils are generally "warmer" than lowland soils. Infiltration rate is high, absoption capacity however is often limited. Most crops, both annual and perennial. can be grown successfully on uplands, except crops which need special conditions such as paddy rice. With proper management upland soils can produce excellent crop yields.

However, the yields of upland crops in developing countries are often far below the minimum to be expected. Most of the staple food is produced on the lowlands, especially where irrigation has to be applied, which is much easier to do on lowlands. Furrow irrigation can be effeciently used on uplands, provided the necessary levelling is carried out. Sprinkler and drip irrigation are well adapated to uplands. In most cases upland irrigation requires a pumplift and for sprinkler and drip irrigation additional pressure is necessary.

In many developing countries insufficient attention has been paid to research, extension and the supply of fertilizer, plant protection materials and revolving funds, which is why upland farmers are often poorer than lowland farmers.

Uplands require very special attention in watershed development. Government services there should be equal to the facilities provided to lowland areas and this is essential for achieving acceptable crop yields. Besides, these lands provide the livelihood for a large proportion of the farming population.

Erosion is generally severe on cultivated uplands and a variety of practices can be applied to prevent erosion and to restore and improve productivity. Large scale farming on gentle slopes is seldom found in developing countries. Consequently, broad base terraces, strip cropping and similar practices are no practical in most developing countries.

On small plots and gentle slopes, contour cultivation, contour ridges and grass strips may be more feasible. Cooperation between farmers is essential, especially for surplus water disposal systems, such as waterways, interception and diversion ditches, and for irrigation facilities. Land consolidation, according to a well designed conservation plan, is certainly of the utmost importance.

On steeper slopes, where simple conservation practices ar insufficient to stop erosion, bench terracing is probably the most effective practice. Here again, land consolidation is an important factor. Well laid-out bench terraces, even on slopes of up to 35%, can prevent erosion, increase water infiltration and should be the most important practice for consideration in developing countries. Generally slopes of up to 25% should be the limit for bench terracing for rotation crops. On steeper slopes, plantations on small contour benches and a permanent cover crop on the slopes are safer and no losses of land occur through terrace risers.

7.3.5 Strip Cropping

As mentioned above, the application of this soil conservation practice is very limited in developing countries with small farms and individual plots scattered over wide areas. To be effective it should be used only on slopes up to 6%.

Where the cultivated land is gently sloping and practices such as terraces cannot be employed because of the shallow soil depth, a strip cropping system with perennials may be successful. This system may be used to protect large fields with long slopes, which have been ploughed and cultivated as one unit and thereby exposed over their entire areas to severe erosion. Under such conditions, apparently harmless runoff from the top of the slopes accumulates momentum, volume, and soil load, until it becomes destructive as it approaches the bottom of the slope. A strip cropping system with perennials in effect breaks up the length of these slopes and thus provides protection from erosion.

There are two variations of perennial strips. The difference between them is that one is a narrow permanent buffer strip, and the other is a wide strip, which allows rotation with annual crops. Whereas the narrow buffer strips cover 20-25% of the land, the wide strips cover 30-50%. The specific conditions of each field determine the type of strips to be used.

There is no set rule for specific plants to be used in these strips except that the most suited are uncultivated close-growing perennials.

The types successfully used so far are found growing naturally, or species which have been successfully introduced in reseeded pastures.

i. Buffer strips

The system is planned on a topographic map (minimum scale-1:2500) with 1 metre contour intervals. Point rows and width differences due to topographic variations are absorbed within the perennial buffer strip in order to leave a uniform tilled field for convenient cultivation between the buffers.

The lower border of the strip is planned on a longitudinal gradient from 0.3-1.0% in order to allow for a ditch to drain to a permanent waterway.

The minimum width of the perennial strip is 6 metres and the distance between consecutive strips is between 30-40 metres, according to slope, erodibility of the soil and rainfall intensities.

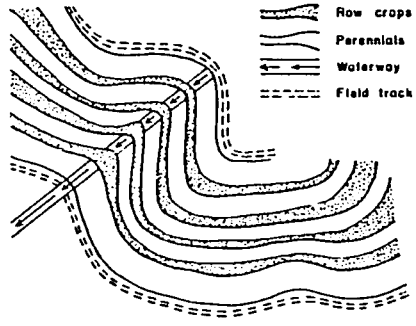


Figure 5. LAY-OUT OF STRIP CROPPING SYSTEM

ii. Wide perennial strips

Planning for these strips is similar to buffer strips except that they are wider and similar in size to those left for annual cultivated crops, thus allowing for rotation. Point rows and topographical variations are also absorbed within the perennial strip, this leaving a uniform width for the tilled strips.

The percentage of the field to be in perennials is determined by the erodibility of the soil and the specific conditions of the field. Usually the more erodible land will have a greater proportion of it in perennials.

7.3.6 Broad Base Terraces

Broad base terraces also have limitations in developing countries, because of the large area essential for their successful application. They should not be constructed on land with slopes over 10%. On steeper slopes the individual terraces would be so near to each other that cultivation would be difficult. Furthermore, on steeper slopes, broad base terraces would not control erosion, even if combined with mulching. There would be a continuous downhill movement of soil between the terraces and especially through the water disposal system, which would require special safeguards and expensive structures to prevent gullying in the waterways and terrace outlets.

This kind of terrace consists of a channel with a ridge on its lower side whose function is: to drain surface runoff, or to absorb runoff. Thus there are drainage and absorption terraces.

Drainage terraces are constructed on areas where:

- the slope is between 3-10%
- the permeability is slow
- the field is dissected by gullies or depressions
- contour cultivation is insufficient to control surface runoff and soil erosion.

Absorption terraces are suited to areas where:

- rainfall is low and rainfall intensities are not excessive
- the slope is less than 6%
- infiltration and permeability are high.

The absorption terrace differs from the drainage terrace in: being level along its length, and in having a longer cross-section.

i. Terrace design

a. Capacity

The terrace capacity is calculated by the following formula:

$$Q = \frac{CIA}{360}$$

Where Q = quantity of water, in m^3 per second, which may reach the terrace.

C = runoff coefficient (surface runoff as percentage of rainfall)

I = rainfall intensity in mm per hour

A = watershed area, in ha (terrace length x distance between terraces)

now Q = AV

Where Q = terrace capacity, in m^3 per second

A = terrace cross-section in m^2

Y = velocity of flow, in m per second

Example: Distance between terraces is 50 mm, terrace length is 500 mm. Then watershed area:

$$A = 50 \times 500 = 2.5 \text{ ha}$$

If surface runoff coefficient C = 0.6, and the 5 year rainfall intensity I = 65 mm/hour, the flow arriving at the end of the terrace is:

$$Q = \frac{0.6 \times 65 \times 2.5}{360}$$

If the terrace cross-section is 1.0 m^2 and the flow velocity 0.3 m/sec the terrace capacity is:

$$Q = 0.3 \times 1 = 0.3 \text{ m}^3/\text{sec}$$

b. Terrace cross-section

The channel and ridge side slopes should be 1:6 to 1:8. Ridge width on the upper side should be not less than 4.0 m so as to enable machinery of all types to be used. The ridge should be 45 cm higher than the channel.

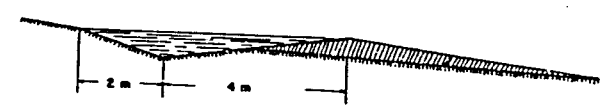


Figure 6. TYPICAL TERRACE CROSS-SECTION

c. Terrace interval

The horizontal distance between two terraces may be determined by the formula:

$$HD = \frac{200}{S} + 10$$

Where HD = horizontal distance in metres

S = percent slope between terraces.

This formula can be used to determine the vertical interval between terraces:

$$VI \text{ (cm)} = 10 \times S + 200$$

or

$$VI \text{ (metres)} = 2 + \frac{S}{10}$$

Where VI = vertical interval between terraces in cm or metres

S = percent slope between terraces

A variable expressing soil erodibility, cropping system and farm management may be added if the necessary values are available. The Universal Soil Loss Equation may also be used provided data are available.

Example: On a 5% slope the horizontal distance is:

$$HD = \frac{200}{5} + 10 = 50 \text{ m}$$

$$VI \text{ (cm)} = 10 \times 5 + 200 = 250 \text{ cm}$$

$$VI \text{ (m)} = 2 + \frac{5}{10} = 2.5 \text{ m}$$

A 20% variation is permissible.

d. Terrace length

The length of the terrace from its beginning to the point where it drains, that is, the draining length of the terrace, should not exceed 600 m. In exceptional cases, where the distance between drainage ways demands it, the length may reach 800 m, but a suitable cross-section and a proper gradient should then be ensured.

The drainage length does not affect the length of the cultivation row since if vegetated waterways or crossable gullies serve as the main drainage-ways, the cultivation row can be continued along the whole length of the field.

e. Length of terrace per ha

The length per ha depends on the slope and the adjusted horizontal interval between the terraces. The topography on any slope will not be uniform and will change along the terrace length considerably. Following the formula $HA = \frac{200}{S} + 10$ the length per ha for an average 8% slope will be 285-290 m, and on an average slope of 4% it will be 160-170 m.

f. Terrace gradient

In selecting the gradient for drainage type terraces consideration should be given to the nature of the soil, spacing and length of the terraces. The permissible velocity of flow should be checked with the expected water discharge for each specific soil. Generally, gradients from 0.3 to 1.0% may be used without causing erosion or waterlogging in the terrace channel.

ii. Other important design factors

a. Drainage-ways

These should be located in gullies or depressions which should be stabilized in various ways. Occasionally, a gully which has eroded to bedrock (in which case there is no danger of further erosion) may be used. The gully banks should then have a permanent vegetative cover.

Where no natural drainage-ways exist in the field, artificial waterways are constructed. It is essential to provide protection against erosion by vegetation or various structures. Terraces should not be constructed unless the drainage way can safely dispose of the runoff. At the terrace outlet into the drainage-way the shape of the cross-section is wide and flat and should be covered with perennial grasses or paved with stones.

b. Farm roads

Since roads are more subject to erosion than other parts of the field, they should be sited where there is no concentration of water, and where water flowing along them can be diverted to an outlet. Roads should preferably be along natural ridges with the terraces crossing them so as to divert the runoff into the terraces, or they should be located on the contour. Where this is not feasible, the runoff may be diverted by logs, small ditches, stone structures, etc. Roads when located parallel to the terrace, should be sited on the ridge or just below it.

Sometimes it is convenient to raise the roads to about 30 cm above the ground. This is desirable to check erosion, and to ensure rapid drying.

A farm road should never cross a terrace along its draining section since this may result in a break in the terrace.

c. Terrace alignment

Terraces may be laid out deviating from the true contour by a steady, continuous gradient, or deviating by a constantly varying grade so as to achieve greater parallelism between terraces.

In the first case marking out in the field is done "blindly", the deviation from the contour being continuous with a gradient that is appropriate to the terrace length. The resulting layout is similar to contour cultivation with the same drawbacks ("point" rows, sharp turns, etc.).

In the second case the terrace layout is done on a topographic map, or by a special method in the field. By means of variations in the terrace gradient and some earth-moving where necessary, "point" row areas can be considerably reduced and sharp bends avoided.

This method has marked advantages but the expense of construction is substantially greater.

iii. Marking out

This must be done accurately in the field with a level in the following manner.

a. The "key" terrace is first staked out: it is usually the upper most terrace of the field, and the remaining terraces are staked out in succession down the slope. The start line of the terraces should be a drainage way or farm road, so as to ensure that the terraces on both sides of this line are in alignment.

b. The stakes are set at 20 m intervals, or even less if the topography is complicated.

c. After the line has been marked out the sharp bends are somewhat straightened by realignment either up - or down-slope. Each deviation from the marked line involves, at a later stage, some grading, so it should not be overdone.

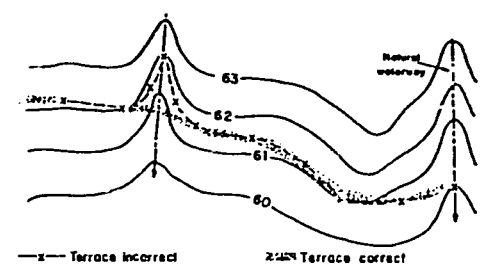


Figure 7. REALIGNMENT OF TERRACES

iv. Construction

Construction equipment includes: disk and mouldboard ploughs, and various graders.

A 6-disk plough, minimum disc diameter 60 cm and 1.5 m total width (or a mouldboard plough), pulled by a D-4 or D-6 type crawler tractor, appears to be most suitable for the purpose. The working speed should be as high as possible so that the soil can be given sufficient sideways "throw". The output should be about 50 m per hour. Graders are efficient and produce a good rate of work, especially motor graders. Even on a relatively steep slope a grader will construct a terrace with a wide ridge, which a plough cannot do. The output should be about 80 m per hour. It should be noted however that a plough and grader may be successfully combined with the plough doing the initial work and the grader finishing off.

Marking the strip. This should be done by marking a second line of stakes down-slope from the staked line, at a distance of 3 m on a moderate slope, or 2.4 m on a steep slope. The soil is then built up on the strip between these lines by the equipment so as to form the terrace ridge.

Moving the soil. In constructing the terrace the plough moves the soil in 8 complete circuits made up of 4 rounds. Additional small corrections may be required.

Grading. As pointed out above the stake line is readjusted at sharp bends (gully, depressions, ridge, etc.), and these sections need to be graded in proportion to their divergence from the staked line. Cuts are made on ridges (not more than 15 cm) while fills are made in depressions with a bulldozer or scraper. The fill may be made by raising the ridge only, or the low spot may be filled in and graded in to the adjoining area. Some 30% additional fill should be allowed for settling.

Checking the terraces and final corrections. After grading, the terrace is again staked along its length and with the use of a level, a longitudinal section of the terrace ridge and channel is made. Final corrections to an accuracy of ± 5 cm, as indicated by the section, are then carried out and rechecked with the level.

7.3.7 Contour Banks

Contour banks on sloping land may well be suitable under conditions of land tenure, small farms and even small individual plots in developing countries, provided that surplus runoff can be drained into safe outlets.

Like broad base terraces, contour banks can be constructed as absorption banks or, with a gradient, as drainage banks. Banks should be sufficiently strong and high to discourage any attempt to cross them with any vehicles or farm machinery and to prevent up and downhill cultivation.

The total cross section should have a width of 3.5 m. The bank channel and its slope should be included in the cultivated area. The downhill slope should be steep, not cultivated, and covered with perennial vegetation which may be seeded or allowed to establish naturally with local vegetation.

Contour banks can be effective on slopes from 2-8%. The vertical interval (VI) should be between 1.5 and 2.0 m. As an average figure a horizontal distance of about 40 m can be assumed = 250 m per ha.

The cut section of the bank should be 25-35 cm deep and about 2 m wide. The fill section adds another 40-60 cm to the total height of the bank = 60-100 cm. The cross section of the cut is therefore 0.5 - 0.75m². The necessity to combine banking with plugs and cuts in depressions and on ridges to smooth the alignment of the bank for easier cultivation, raises the cut and fill quantities to about 0.83 m³ per metre length. A round figure of about 200 m³ per ha is a safe estimate.

Contour banks as described would occupy about 7.5% of the total area but only 3% (the downhill, steep slope) would be lost to cultivation.

i. Lay-out and construction:

The lay-out should be done with a surveyor's level and the pegs should be spaced from 10-20 m apart, according to the topography. The gradient in the bank channel should be between 0.3 and 1.0% according to soil type.

Construction can be done by hand or by bulldozer. Plough or motor graders are not recommended for this work.

If done by manual labour, 2-3 m³ of soil movement per man day can be expected = 70-100 man-days per ha. An 80 hp bulldozer should move about 50-70 m³/h or require 3-4 hours/ha to accomplish the work.

A heavy 200 hp bulldozer with power-shift might move 140-200 m³/h or require between 1.0 and 1.5 hours/ha to accomplish the work.

ii. Cultivation

It is strongly recommended that reversible ploughs be used for cultivating the land between the banks. This balances the down-hill movement of the soil and prevents rapid siltation of the bank channel. Furthermore, the last dead furrow keeps the bank channel free of obstructions.

7.3.8 Interception Ditches

Interception ditches are constructed in the same manner as contour banks but sometimes have to be much stronger, depending on the size of the catchment and the runoff coefficient above the ditch. Their main purpose is to prevent runoff water from areas above such as hillsides from entering lower lands which are protected by other soil conservation practices, and also to divert water from active gully heads.

Any area above an interception ditch which produces much sediment should be protected by a vegetative cover or mechanical measures to prevent sediment accumulating in the ditch. Interception ditches should be located so that water empties into established or natural outlets and protected water disposal systems. Across irregular slopes, the ridge of the diversion ditch should be reinforced where it crosses draws (silt traps). Lay-out and construction methods should be the same as for contour banks (see 7.3.7). The depth and width of cut and fill is determined by the area above the interception ditch and its physical condition. To prevent accelerated siltage only the maximum allowable velocity of water should be used in design parameters.

7.3.9 Diversion Ditches

Diversion ditches are small channels with banks which have a slight slope towards a well prepared and safe outlet for the disposal of surplus water. They are used to effectively reduce the length of slopes on arable land and/or to break up concentrations of water in depressions on long gentle slopes.

Simple diversion ditches may be constructed during land preparation with a plough, by ploughing twice and leaving an open furrow and the resulting downhill fill as a mechanical barrier, but this should only be done on gently sloping land.

On such land shallow depressions should be crossed by slightly elevated fill sections of the diversion ditch, in order to prevent the start of gullying, and at the same time allow the depressions to gradually level out by siltation.

A water disposal system for these simple diversion ditches is necessary, in the form of grassed waterways, or strips of land with a close vegetative cover.

The velocity of water in shallow diversion ditches should be limited to the lower range of the permissible velocities in the specific soil and the pattern of rain intensity. Accordingly, the fall of such diversion ditches should be between 0.5 and 1.0% and adjustments for water velocity should be made in the design width of the ditch.

7.3.10 Water Disposal Systems

The problem of runoff disposal on sloping land is how to slow down the flow of water in order to prevent scouring in drainage channels. To this end the channels are designed with a large frictional area (large hydraulic radius). But, whereas in humid regions, or on irrigated land, it is most convenient to protect the channels by means of vegetation, under dryland farming conditions this solution is not always appropriate.

Therefore, use is often made of naturally stabilized drainage ways or of those in which the slope is reduced by drop-structures of various types.

Natural drainage ways are very efficient in disposing of runoff for the following reasons. Being located in depressions, surface runoff and sometimes sub-surface seepage, collect in them naturally. Thus, no artificial diversions are needed. Usually, the slope in such channels approaches the required design slope, and the construction expenses are less than in artificially excavated channels. Finally and most important of all, experience has shown that an improved natural channel drains more efficiently than an artificially excavated one.

i. Improved natural drainage ways

The main purpose of improvement is to facilitate crossing the channel with all types of vehicles and machinery and to serve as a recipient of water from outlets of ditches, banks and terraces.

In order to permit crossing, the maximum side slopes of the channel should not be greater than 1:8. The width, and to some extent the depth, depends on the flow for which the channel is designed. These requirements are generally present in natural channels and, therefore, only partial shaping is required, with the objective of ensuring that the channel, throughout its entire length, has at least the minimum design cross-section. The rule is that runoff must not be diverted into a drainage channel until it is erosion-resistant to the flow.

ii. Grassed waterways

The cross-section of waterways depends on the slope, soil texture and the area to be drained. The rainfall may vary widely in different ecological zones. However, rainfall intensities may be higher in low annual rainfall areas than in high annual rainfall areas. Consequently the quantity and velocity of runoff water may not differ very much. For field estimates, standard figures are given in the table below, but they should be used as guides only and might have to be adjusted according to local conditions

Waterways should have a parabolic cross-section and be covered densely with locally adapted grasses. The deepest cut should be between 0.5 and 1.0 m.

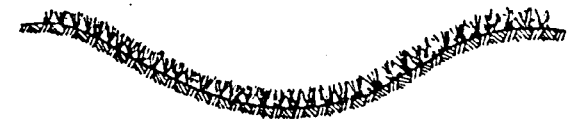


Figure 8. CROSS-SECTION OF A GRASSED WATERWAY

The grasses used in waterways have to be adapted to the local climatic conditions. Generally, grasses which spread by rhizomes (e.g. Cynodon dactylon) are the best types for the purpose.

In semi-arid zones drought resistance should be especially considered. Bunch type grasses with strong stems should always be avoided. However very soft and dense bunch grasses (e.g. Eragrostis curvula) which bend with the flow of water, and create a roof-like cover, are often successfully used. A very careful review of the available local or introduced species of grasses should be carried out before selecting one, or a mixture of good grasses which will protect the waterway from damage by erosion. Seedbeds have to be prepared carefully. A waterway in which a seed bed has been prepared is very susceptible to erosion, and soil and seeds may be swept away. It is a good practice therefore, after seeding, to cover the soil with a mulch, or else to use mechanical structures or sod strips.

As a rule of thumb about 50-75 m³ of earth movement will be required per ha of drainage area. This can be done by manual labour or by heavy equipment as indicated in the table below

STANDARD FIGURES PER HA OF DRAINAGE AREA

	Man days	200 hp Bulldozer hrs	150 hp Grader hrs
Manual labour only			
Earth moving	25		
Shaping, seeding, repairs	20		
	45		
Heavy equipment			
Shaping, seeding, repairs	20	0.5	0.1

1 kg of grass seeds and 10 kg of chemical fertilizers per ha should be applied for both methods

Care of grassed waterway

The waterway should always be crossed with raised implements, otherwise the vegetation will be destroyed.

In the case of implements which cannot be raised, crossing lanes are provided about 10 m part. As the implement nears the waterway it should veer gradually towards the nearest downslope crossing lane so that runoff can drain freely into the waterway.

Before the onset of the rains, the grass in the waterway must be cut, so that the flow of water can proceed smoothly without causing eddies. Light grazing may be allowed in the waterways provided about 15 cm plant height is left.

Fertilizer should be applied regularly according to the requirements of the grass stand.

iii. Parallel ditch system with waterways

This system may be used on sloping land (up to no more than 8%) which is irrigated by furrow, sprinkler or drip irrigation. Grading (levelling) is essential to give the land and the furrows the desired slope. The cross-slope itself is not eliminated. Depending on the topography and the distance the earth is moved, bulldozers, graders and/or scrapers can be used for this kind of levelling. The average earth movement per ha varies between 300 and 500 m³. Different example layouts are shown in Figures 11 and 12. Exact topographic maps have to be prepared.

a. Survey and layout

The survey is done using a grid at 20 x 20 m intervals. On difficult topography, the grid spacing is reduced to 15 x 15 m or even to 10 x 10 m. The accepted mapping scale is 1:500.

The stakes used are 1 m long. They should be left in place until completion of the grading.

b. Location

Waterways should preferably be located in natural depressions. This is the most efficient way and also the cheapest, since it saves on grading. When, however, for various reasons it is not practicable to choose this method, then the waterway may be located on the field boundary at the end of the irrigation laterals. While this method usually requires a great deal of grading, it has the advantage of permitting furrow irrigation. The pipe is located on the ridge, the rows drain away from the pipe on both sides of it, and the distance between two waterways is equal to the distance between mainline pipes or uniform canals, usually 200-400 m.

Since the waterway must allow for cutting, grazing and crossing with machinery, the side slopes are fixed as follows:

Waterway less than 50 cm depth - 1:6 minimum
Waterway more than 50 cm depth - 1:8 minimum

The waterways are excavated with a scraper during the grading operation and the excavated soil is used for filling in low places.

c. The drainage ditches

These are given a slight gradient and the distance between them is found from the formula:

$$Q = \frac{C\ I\ A}{360}$$

though distances of 36 or 24 m meet the usual requirements for sprinkler irrigation. The ditches should be located midway between lateral irrigation pipes so that they may be cultivated and maintained more easily. The gradient along the ditch varies between 0.5 and 1.5 percent. The use of variable gradients allows greater latitude in keeping the ditches parallel and in eliminating "point rows". The length of the ditch should not exceed 200 m since its small cross sectional area is capable of carrying only small flows.

The excavation is done by a scraper. A narrow channel 15 cm deep and 2.5 m wide (one scraper width) is opened. The excavated earth is placed on the lower side, forming a 10 cm high ridge, thus increasing the cross-section.

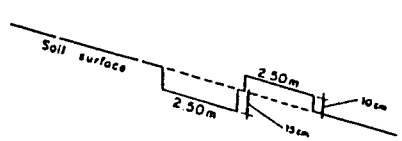


Figure 9. INITIAL CROSS-SECTION

After completing the excavation of the channel, the ridge heights and the grade along the channel are checked with a field level and corrections made where necessary. The height difference between the channel and the ridge should be approximately 25 cm.

The final shape of the ditch is obtained after the field is ploughed. It then becomes a wide, shallow ditch which merges into the field on either side.

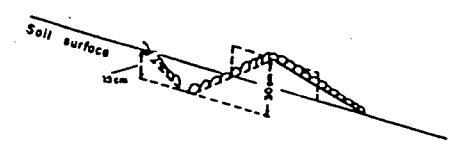


Figure 10. TYPICAL FINAL SECTION OF DITCH

iv. Capacity of waterways

The formula $Q = \frac{C\ I\ A}{360}$ is applied in determining the quantity of water to be discharged by a waterway where:

Q = Quantity of water in m³ per second which may reach the waterway

C = Runoff coefficient (surface runoff as percentage of rainfall)

I = Rainfall intensity, mm per hour

A = Watershed area in hectares to be drained by a waterway.

The runoff coefficient varies widely with slope, soil texture and permeability and with the various soil conservation practices applied on the land. A 5-10 year intensity should be selected. As a rule of thumb, the C coefficient is likely to vary between 0.3 and 0.6.

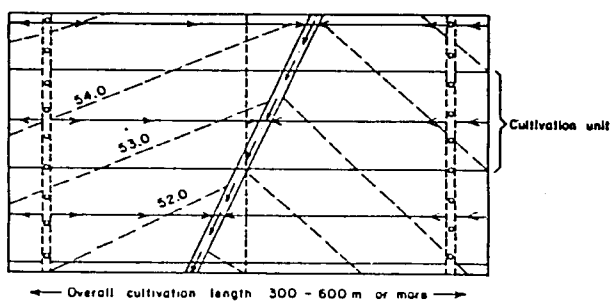


Figure 11. EXAMPLE LAYOUT OF PARALLEL DITCH SYSTEM WITH WATERWAY

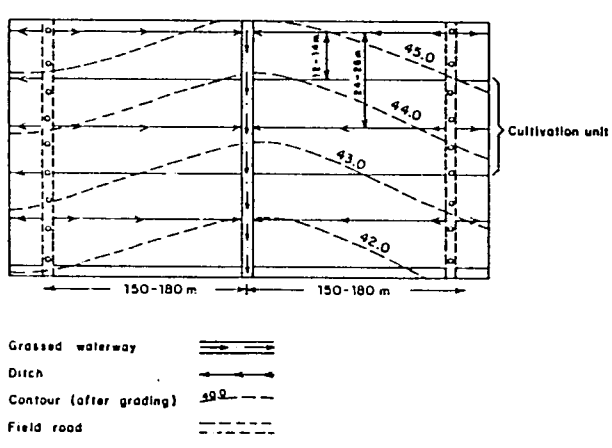


Figure 12. EXAMPLE LAYOUT OF PARALLEL DITCH SYSTEM WITH WATERWAY

Table 4. GUIDE TO SELECTION OF VEGETAL RETARDANCE

Stand	Average length of vegetation	Degree of retardance	Stand	Average length of vegetation	Degree of retardance
	Longer than 0.75 m	A = very good		Longer than 0.75 m	B
	0.3 - 0.6 m	B = good		0.3 - 0.6 m	C
Good	0.15 - 0.25 m	C = fair	Fair	0.15 - 0.25 m	D
	0.05 - 0.15 m	D = good		0.05 - 0.15 m	D
	Less than 0.05 m	E = very poor		Less than 0.05 m	E

Table 5. PERMISSIBLE WATER VELOCITIES IN CHANNELS, DITCHES AND WATERWAYS

Soil Texture	Permissible Velocity - m/sec				
	Bare Channel	Channel Vegetation			
		Retardance	Poor	Fair	Good
Sandy silt		B		0.90	1.20
Sandy loam	0.45	C	0.45	0.75	1.05
Silty loam		D		0.60	0.90
Silty clay loam		B		1.20	1.50
Sandy clay loam	0.60	C	0.75	1.05	1.35
		D		0.90	1.20
Clay		B		1.50	1.80
	0.75	C	0.90	1.35	1.65
		D		1.20	1.50

With regard to the capacity of water discharge in m^3 per second, the formula $Q = AV$ is applied where:

Q = Waterway capacity in m^3 per second

A = Waterway cross-section in m^2

V = Velocity of flow in m per second.

In grassed waterways the retardance factor of the grass cover and its resistance to erosion has to be considered in selecting the permissible water velocity (Tables 4 and 5). The cross section of waterways is then calculated accordingly.

7.3.11 Bench Terraces with Soil Risers

Bench terracing is probably the most effective soil conservation practice on sloping land. It is also the only possible practice to reclaim land for cultivation on slopes over 8-10% and up to 35% - sometimes even up to 55% - for the production of sustained yields of (high value) agricultural products.

Bench terracing is always a major reclamation job, whether carried out on steep cultivated and eroding slopes or on lands which are at present under less intensive use, such as grazing, but have sufficiently deep soils to be permanently converted into agricultural land. Bench terracing is often called "Land Conversion", a very fitting name for this activity which "converts" badly eroding or under-used areas into highly productive crop land.

The most important first step in successful land conversion is the selection of the sites to be converted. The following factors have to be considered:

(a) good soil texture with sufficient depth

(b) topographic features and crop adaptation

(c) consent of the farmers involved

Regarding (a). Very sandy and coarse soils should be avoided. Conversion should start from good loamy sands onwards to the heavier textured soils. The minimum depth on the cut section should be not less than 40-50 cm (after the cut) for annual crops. Plantations need deeper soils for the development of root systems. Trees should therefore always be planted on the fill section near the riser, where the soil is the deepest and most fertile.

Regarding (b). Areas with very broken topography should be excluded. Depending on the intended cropping pattern, annual crops should be planted on terraces from 5-25% slope. Orchards may be planted up to over 35% slope with very narrow bench strips, if possible under permanent cover crops, the important factor being the air and root space between the trees.

Regarding (c). Bench terracing without the consent and interest of the farmers involved has been unsuccessful and without consent should be avoided. Many cases have been observed in which farmers have agreed to conversion under pressure by officials. These areas are in most cases poorly farmed or not cultivated at all. These factors should be very seriously considered in casesof any new intensive drive for land conversion

i. Design and layout

In designing terraces, natural features should be used, where possible, in siting waterways, paths, etc.

A base line at right angles to the contours (directly up and down the slope) should be established near their centre, and on a line of approximately average slope of the area to be terraced. Using a level, pegs should be placed at one metre vertical intervals on the base line. The level will have to be set up several times if the land is steep (see Figure 13).

These pegs form the base from which the "contour lines" are pegged out on the ground. Once again using the level, pegs are placed at the same elevation, about 10 m apart (or closer if the terrain is irregular) and then joined with a rope. After setting out, pegs are realigned, to smooth out the contour lines for easier construction and subsequent cultivation between them.

During setting-out the position of the waterways should be determined. Where possible these should be sited in small natural depressions if they occur, but on no account should they be more than 100 m apart. The minimum width for a waterway is 50 cm at the bottom but may be as wide as 4 m for large catchment areas and steep slopes. The bed of the waterway has to be level, thus spreading the water, and well sodded or seeded with grass, in order to reduce water velocity. Also it is necessary to construct drop structures to reduce velocity. These should be constructed of stone, but as an alternative, well sodded drops may be used.

If the area to be terraced does not extend to the top of the watershed, the runoff from above must be diverted into waterways passing through or around, the terraced area. Therefore, it is necessary to construct interception ditches. The maximum length of the ditches should be half the distance between the waterways, and their grade should be between 0.5 and 1.0 percent.

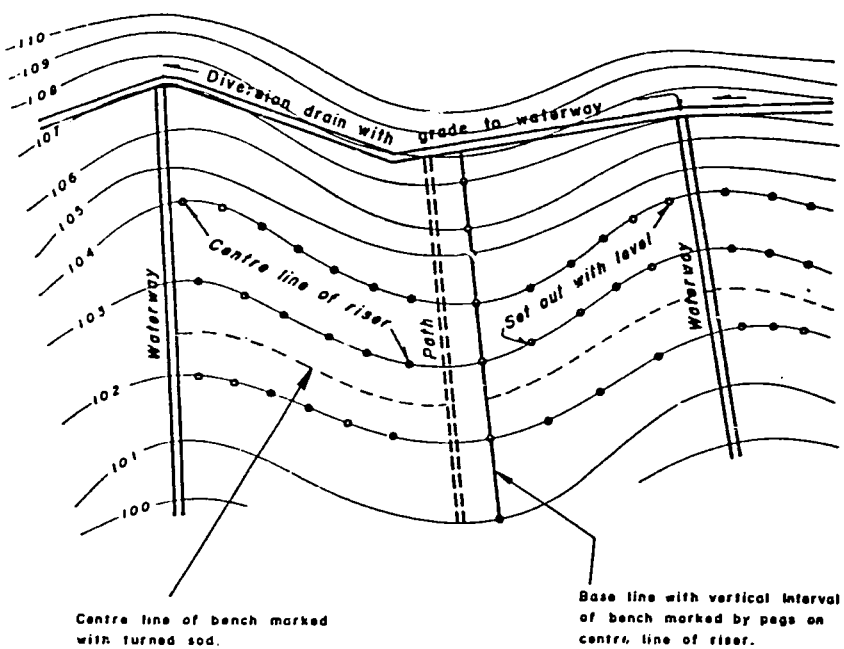


Figure 13. LAYOUT FOR BENCH TERRACES (not to scale)

ii. Construction

Since each individual terrace is formed from equal volumes of cut and fill, construction of bench terraces may start at any point after setting out has been completed. However it is recommended that work be commenced with the construction of the interception ditch, if necessary, and then to proceed downhill. Thus there should be no problem with runoff during construction. Furthermore, the risers should be sodded or seeded with grass as soon as they are completed.

The surplus of fill material (due to natural compaction of the soil) should be placed on the fill side of the centre line of the bench. In normal circumstances this makes the outside of the bench 10 cm higher than the centre at the time of construction.

This fill material soon settles to form an almost level terrace. In order to prevent water spilling down the riser, a ridge of 10 cm higher and 20 cm in width is built along the lip of the riser. This material is obtained from a drain of similar dimensions at the bottom of each riser (see Figure 14).

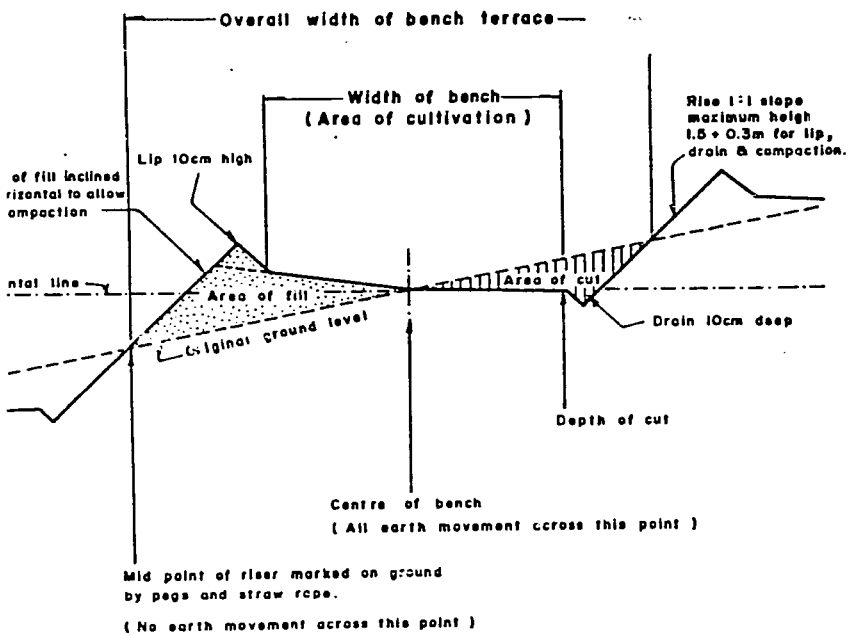
It is emphasised that it is most important that the terrace should have a slight back-slope, otherwise runoff down the riser would cause severe erosion.

Waterways should be constructed with a series of drops, to reduce the velocity of runoff water, and if possible the drops should be made with stone. Waterways and their sides should be well sodded or seeded throughout their entire length. The position of the top of the drops should be near the original ground level, between the centre of the bench and the top of the riser. Furthermore, the drain at the bottom of each riser should run into the waterway at the same level (see Figure 15).

On completion of the earth-moving work, the risers should be trimmed to a 2 to 1 slope and sodded or, more economically, seeded with well adapted grasses and legumes.

If sodding is to be used, it should be carried out in continuous strips of not more than 20 cm apart.

Risers may be protected from erosion by seeding, and this method requires much less labour than sodding. Also it reduces the temptation to obtain sods from other areas susceptible to erosion.



NOTE : FOR DETAILS OF AREAS AND VOLUMES AT DIFFERENT PERCENTAGE SLOPE SEE TABLE 6

Figure 14. CROSS SECTION OF BENCH TERRACES (not to scale)

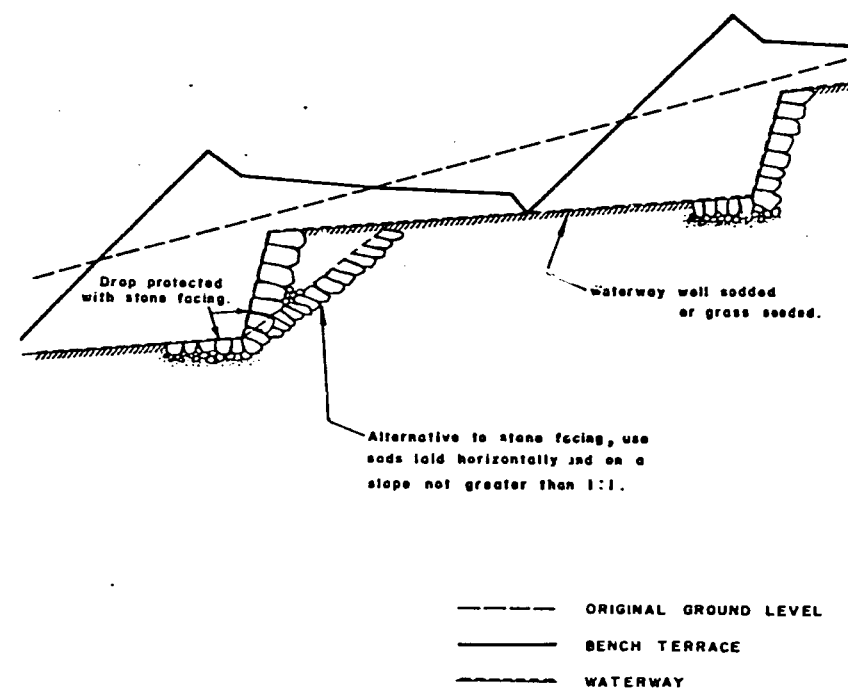


Figure 15. CROSS SECTION THROUGH BENCH TERRACE AND WATERWAY (not to scale)

As an example, Table 6 summarizes the physical characteristics of bench terracing with a standard vertical interval (VI) of 1 m. On slopes up to 10% a lower VI should be used depending on the crops or rotation and farm machinery to be used. On slopes over 25% no bench terracing with 1 m VI should be carried out. In fact such slopes should not be used for arable crops.

It is evident from Table 6 that the width of cultivateable benches on a slope of 25% is only 2.5 m out of a total width of 4.0 m of terrace. 1.5 m are lost to the riser. On a slope of 35% the width of the bench is only 1.36 m and 1.5 m are occupied by the riser. 25% of slope should be the absolute maximum for bench terracing for arable crops if animal or mechanical power tools are used. Preferably the limit should be set at 20%.

On steeper slopes narrow benches may be cut but only for tree plantations. The VI to use between these benches depends on the spacing required for the specific tree crop. There is no loss of land for risers as the root and air space is provided by the horizontal distance between benches. For each tree a wider basin should be constructed, by cutting into the slope and filling the material on the downhill side.

A permanent and dense cover crop is essential and only the individual basins for each tree should be weeded. This system is not only very affective against erosion but the cost is much lower as much less earth movement is required.

If only manual labour is used in cultivation, narrow benches of 1 m width can also be used for arable crops. On a slope of 30% the risers would be only 0.3 m high and the total earth movement would be about 750 m³/ha.

For tree crops on the same slope, e.g. coffee planted with a spacing of 3 m between the rows, only every third bench would have to be cut, or about 250 m³/ha of earth movement for the benches, plus an additional 100-150 m³ for the individual basins - a total of 400 m³/ha without any loss of area for risers. The standard bench terrace with a VI of 1 m on a 30% slope would require 1 642 m³/ha of benches (see Table 6).

Bench terraces can be constructed by manual labour or a combination of machinery and manual labour.

Table 7 gives the approximate labour requirements for bench terracing if done only by manual labour.

Table 6. AREA AND VOLUME FOR BENCH TERRACING FOR DIFFERENT PERCENTAGE SLOPES WITH BENCHES AT 1 m VERTICAL INTERVAL

Ground slope . . . . . %	5	10	15	20	25	30	35
Width of benches[1] . . . . . m	18.50	8.50	5.17	3.50	2.50	1.83	1.36
Width of bench terraces . . . . . m	20.00	10.00	6.67	5.00	4.00	3.33	2.86
No. of benches per 100 m of slope -	5	10	15	20	25	30	35
Maximum depth of cut (excluding drain) . . . . . m	0.47	0.45	0.42	0.40	0.37	0.35	0.32
Area of benches[1] per ha . . . . . %	0.925	0.850	0.775	0.700	0.625	0.550	0.475
Slope area of riser per ha . . . m²	919	1 838	2 758	3 667	4 596	5 515	6 434
Volume of cut per ha of bench terraces . . . . . m³	1 175	1 135	1 077	1 020	963	903	847
Slope area of riser per ha of benches . . . . . m²	994	2 162	3 559	5 253	7 354	10 027	13 545
Volume of cut per ha of benches m³	1 270	1 335	1 390	1 457	1 540	1 642	1 783

1/ Area on which cultivation can take place.

The stable slope may be achieved in two ways:

- by transporting the soil from the upper part of the terrace to its lower part with earth moving equipment.
- by leaving it to be done by cultivation and nature, over a period of years.

When the area is being reclaimed for orchards, it may sometimes be worthwhile to sub-bench the individual rows before planting.

With rotation crops it is advisable to let nature and cultivation do the job of benching. The cost is thereby reduced and it is easier to build up and maintain soil fertility

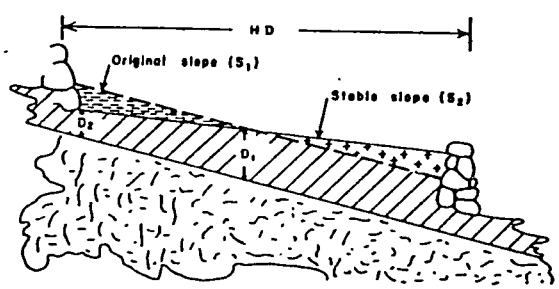


Figure 18. SKETCH OF BENCH TERRACE CONSTRUCTED ON THE PRINCIPLE OF THE STABLE SLOPE

iii. The retaining wall

The wall is constructed from stones collected on the spot. As a rule, close and low retaining walls are preferable to high walls set far apart.

The height of a stone retaining wall is given by:

$$H = (H_1 + X_1) + (H_2 + X_2)$$

Where H = height of wall

H_1 = depth of soil: presumed to be lost by creep, at the foot of the wall

H_2 = depth of soil presumed to be deposited near the wall

X_1 = safety factor (usually 30 cm)

X_2 = safety facto .usually 10 cm)

The formula is readily understood when it is considered that the wall on its lower side must be sunk into the ground by an amount equal to the depth of soil which is expected to be removed by creep (plus the 20 cm safety factor), and on its upper side must rise above the ground surface by an amount equal to the deptn of deposition expected (plus the 10 cm safety factor).

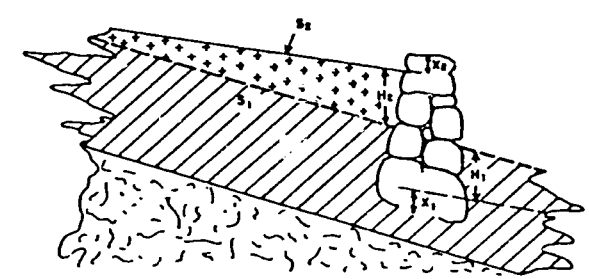


Figure 19. SKETCH OF STONE RETAINING WALL

iv. Drainage of gravitational water

It may be frequently observed, following rainfall, how water percolating through the retaining wall wets the terrace below it. In order to drain this water, furrows are opened at the foot of every retaining wall. These furrows need not have a large capacity, since they only conduct small quantities of water, but they need a continuous longitudinal grade. For this reason it is important to grade the strip along which this furrow is to run.

This can be expressed as

$$HD = \frac{H_1 + H_2}{S}$$

Where HD = horizontal distance, in metres,

H_1 = depth of excavation in upper part of terrace, in metres,

H_2 = height of fill in lower part of terrace, in metres,

S = slope, metres/metre.

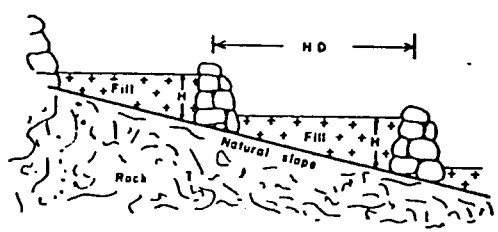


Figure 16. SKETCH OF BENCH TERRACE CONSTRUCTED BY FILL

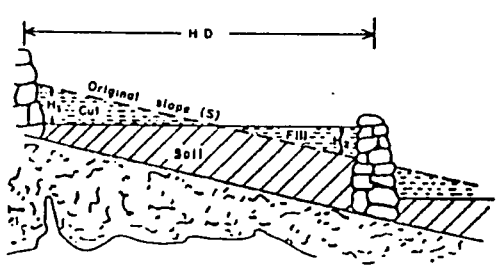


Figure 17. SKETCH OF BENCH TERRACE CONSTRUCTED BY EXCAVATION AND FILL

This method, though cheaper than the previous one, is still fairly expensive. Level bench terraces have many advantages but suffer from the following drawbacks:

- They are narrow and machinery cannot be easily used on them.
- Many high retaining walls are needed, thus steeply raising the cost of reclamation on the one hand, and on the other hand making access to the benches more difficult, thereby increasing the cost of tillage.
- Where the soil is initially shallow, the terrace, after its construction, has relatively deep soil on its lower part, while on the upper part the soil is often too shallow for the plant's requirements.

Consequently, it is recommended that stone wall bench terraces be used primarily for permanent tree crops where the trees can be planted in the fill section only.

ii. Determining the interval according to the presumed stable slope

The disadvantages mentioned above may be largely overcome by designing bench terraces on the principle of the stable slope. This design is especially useful in the case of rotation crops, where an artificial stable slope of 3-8% can be maintained by using a reversible plough or disk, as already strongly recommended. The stable slope changes for different soils. Local observations and experience should be noted and applied. It should be possible to reach fairly exact conclusions from reviewing the condition of a given cultivated soil and comparing its stability against erosion seen on different slopes. The terrace interval can be calculated as follows:

$$HD = \frac{2(D_1 - D_2)}{S_1 - S_2}$$

Where HD = horizontal distance, in metres

D_1 = present depth of soil on the area, in metres

D_2 = minimum soil depth required by the crops, in metres[1/]

S_1 = present slope, metres/metre

S_2 = presumed stable slope (natural or artificial), metres/metre

1/ With rotation crops this depth is that of the upper part of the terrace, at the foot of the retaining wall. In the case of orchards the depth is that of the root zone of the trees in the uppermost row of the terrace.

Table 7. LABOUR REQUIREMENTS 1/ FOR CONSTRUCTION OF BENCH TERRACES AT 1 m VERTICAL INTERVAL WITH GRASS SEEDED RISERS

1. For 1 ha of bench terraces (overall area) 2/

Ground slope . . . . . %	5	10	15	20	25	30	35
Earth moving per ha of terraces standard 3 m³ per . . . . . m/d	392	379	359	340	321	301	283
Seeding and fertilizing of risers standard 1 000 m² per . . . . . m/d	1	2	3	4	5	6	7
Lime application . . . . . m/d	9	9	8	7	6	6	5
Waterways per ha of terraces standard 10 m cut & sodded per . m/d	10	10	10	10	10	10	10
Total m/d per ha of bench terraces m/d	412	400	380	361	342	323	305

2. For 1 ha of benches (Area of cultivation) 3/

Ground slope . . . . . %	5	10	15	20	25	30	35
Earth moving per ha of benches standard 3 m³ per . . . . . m/d	424	445	464	486	514	548	595
Seeding and fertilizing of risers standard 1 000 m² per . . . . m/d	1	3	4	6	8	11	14
Lime application . . . . . m/d	10	10	10	10	10	10	10
Waterways per ha of benches standard 10 m cut & sodded per m/d	11	12	13	14	16	18	21
Total m/d per ha of benches . . m/d	446	470	491	516	548	597	640

1/ Labour standards: 1. Earth-movement 3 m³ per m/d.
2. Seeding and fertilizing 1 000 m² per man-day (m/d).

2/ The overall area (gross area) is the total horizontal area comprised of the benches and the risers.

3/ The area of cultivation (net area) is only the area of benches which are cultivated. The area of the risers which are under permanent plant cover are not accounted for.

If heavy equipment is used a 200 hp bulldozer would move about 100 m³/h. In addition a minimum of 50-80 man-days/ha would be required for final shaping, seeding, sodding, etc. Brush control and root removal would require an additional 60-100 man-days/ha. (All the above figures are for gross hectares).

7.3.12 Bench Terraces With Stone Walls

The construction of bench terraces with stone walls is justified where stone can be found in adequate quantities close to the site, and potential productivity of the land justifies the expense. However where there are many surface stones cultivation may be restricted.

The construction of stone wall terraces at intervals on the contour not only protects the land from erosion but simultaneously reduces the number of stones, which facilitates cultivation and increases crop production. To justify the relatively high cost, intensive land use is necessary.

Bench terraces with stone walls can be used for annual crops and perennial tree plantations. The latter are likely to produce the highest return on the investment, except in cases of special high value annual crops. Furthermore, tree crops require less cultivation.

All remarks regarding the use of natural features in designing terraces in Section 7.3.11, apply to terraces with stone walls.

1. Determining the interval between bench terraces of level cross-section

The horizontal distance is a function of:

- the height of the retaining wall
- the slope of the land

This can be expressed as

$$HD = \frac{H}{S}$$

Where HD = horizontal distance, in metres

H = height of retaining wall, in metres

S = slope, metres per metre

This formula applies only to those bench terraces constructed by building a retaining wall and filling it with soil brought in from outside (Figure 16). This method, however, is the most expensive and is only used when there is insufficient soil depth on site to be reclaimed. Usually, bench terraces of level cross-section are constructed by moving soil from the upper part down to the lower part (Figure 17).

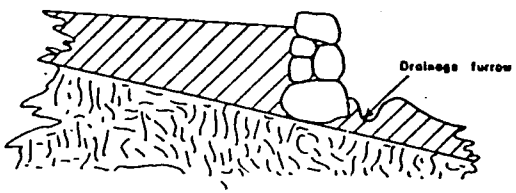


Figure 20. THE DRAINAGE FURROW

v. Disposal of runoff water

In many countries a common practice is to divert the runoff from the cultivation furrows and retaining walls into deep, narrow, ditches made of stone, concrete or earth, which run straight down the slope or diagonally down it. Since such ditches cannot be crossed by machinery, they cannot be used in areas where cultivation is mechanized. On the other hand, wide, shallow, vegetated waterways, crossable by machinery, which are effective on moderate slopes, are not a practical proposition on slopes exceeding 15%, since the vegetation will not supply the necessary protection. There are two possible solutions:

a. Combining vegetated waterways with drop structures of stone or other material

The drop structures in the waterway are an extension of the retaining walls. Their height is lower than that of the wall and is determined by the amount of flow in the waterway. Where the retaining walls are set far apart, it may be necessary to construct additional drops in the waterway. The area of the waterway itself is sown or planted with perennial grasses for complete protection.

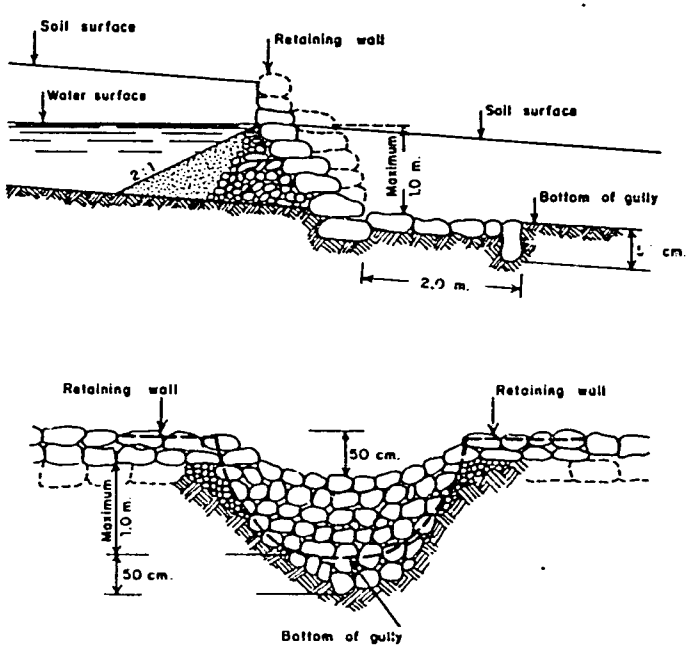


Figure 21. SKETCH OF A DROP STRUCTURE

b. Paving the waterway with stone

Paving the waterway with stone is rather costly, but the method has the particular advantage that the waterway can then be used as a field track. The provision of tracks on steep areas is a substantial fraction of the total cost of reclamation, so that combining the waterway-with the field track is a promising solution.

Cost of construction

The cost of constructing stone walls is high. It is impossible to give standard costs per ha because in each location and for each crop different requirements prevail. However a few indications can be given for estimating the cost.

Stone walls should have a width of about 0.3 m on the top and not less than 0.8 m at the bottom if they are 1 m high. At least 0.3 m should be buried in the ground as a safe foundation. This depth of foundation has to be calculated after the removal of soil for the fill in the lower terrace.

1 m length of terrace will require 0.55 m³ of stones.

Building of stone terraces is a specialized job requiring much experience. One skilled and one unskilled labourer should be able to use 1 m³ of stone (including excavation of the foundation) per day.

.4 SOIL AND WATER CONSERVATION ON PASTURE AND RANGE LAND

7.4.1 General

All lands in this land utilization group are used exclusively by livestock of different kinds. They should not be used for cultivation. On the other hand grazing and/or cutting forage must be strictly controlled. Improving and maintaining the ground cover is therefore the principal conservation measure. However, additional physical conservation practices are often required to reclaim badly eroded lands and to prevent erosion in specific problem areas. The improvement and good management of these lands are of the utmost importance, especially in the steep mountainous parts of a watershed, which are a major source of erosion and runoff in the highlands and of siltation and floods on the lowlands. Furthermore a sound and well established livestock industry may often be a major source of income of farmers in the mountainous parts of watersheds with their limited areas of arable land.

In semi-arid and arid zones where no irrigation water is available and where cultivated crops are under constant danger of failure, pasture and range may be the only safe use for the land which, with proper management and improvement, may still produce satisfactory yields of animal feed. Furthermore, water yield may be improved by replacing low grade brush vegetation with a dense grass cover, which would at the same time make the establishment of successful animal husbandry possible.

Actually, every management activity to improve and maintain production on grassland would at the same time be an important factor in protecting the land against water and wind erosion.

7.4.2 Management and Soil Conservation

The first and most important management practice is the proper stocking of pasture and range, and the establishment of rotational grazing (for which fencing is necessary). Stocking may vary widely, for example from 0.5 to more than 100 ha per animal unit, according to climate and soil conditions. Rotational grazing is essential to give the grass a period of rest after grazing to allow re-growth. The correct grazing and rest periods differ in the various climatic zones. There may also be rest periods for "on the land" storage of grass for consumption in dry seasons.

The general tendency throughout the world, in developed as well as developing countries, has been to overstock grazing land far above its carrying capacity, often by adjusting the capacity to exceptionally "good" years, without readjusting stock numbers in "bad years", which are generally much more frequent and near the average to be expected.

Overgrazing destroys the most palatable and useful species in the plant mixture and reduces the density of the plant cover, thereby increasing the erosion hazard and reducing the nutritive value and the carrying capacity even more. It is a vicious cycle which has created many man-made deserts over long periods of misuse.

i. Fencing

Fencing is used to divide range or pasture into a number of grazing paddocks. For rotational grazing on range, three to four equal sized paddocks each grazed for a number of days are needed. Paddock size varies according to the size of the range area. For pastures a larger number of smaller paddocks is recommended, for more intensive use.

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Although herding and tethering can be used for grazing control on small areas (1-5 ha), on larger areas fencing is required. Both permanent and electric fencing can be used. The former is recommended on large range areas (over 50 ha) the latter on re-seeded pastures (3-25 ha) and small range areas (10-20 ha). Permanent fencing must be installed according to specific standards but at reasonable cost.

Wooden, concrete or iron posts (210 cm long) set 80 cm deep and spaced 8 m apart, carrying 4 or 5 strands of fencing wire with bracings for corners and changes of direction are recommended. Wire spacers are fixed every 2 m along a wire fence line and the wire must be strained tight before attachment to the posts with wire or staples. If the climate permits, use can be made of live fence posts. Cuttings of Glericidia sepium and similar small trees are recommended for this purpose in the humid tropics.

Electric fencing consists of a high voltage control box, battery or mains operated, to energize the fence, wooden or metal corner posts and intermediate posts, and either plain wire, barbed wire, or polycord with insulators. For cattle a single wire, and for sheep two wires, should be strained tight before attachment to the insulators on the posts.

ii. Brush control

Brush can be controlled by brushing on a concentrated solution of suitable herbicide (e.g. 2.4.D) on the stumps of trees and shrubs which remain after clearing. This method prevents pollution and danger to other crops. Some shade trees should be left for the livestock as shelter and shade in hot sunshine and for browsing in very dry seasons.

Spraying of the total area should not be permitted. The danger of damage to cultivated crops near the sprayed range land is very high. It also destroys some of the useful species in the plant mixture of the grazing lands.

Brush clearing can sometimes be carried out by chaining. However this method is not recommended because it removes all trees and brush, including the useful woody vegetation.

iii. Watering points

The provision of sufficient and well distributed watering points provides necessary drinking water but also enables uniform use to be made of the grazing land (by spreading the animals over the whole area and not too far from a water point - for small dams, see Chapter 8).

Watering points must be well selected and carefully prepared. The concentration of large numbers of animals in a restricted area often causes heavy destruction of the environment and greatly increases the hazard of soil erosion by wind and water. All precautions to avoid these dangers must be taken, including such measures as paving, prevention of the creation of permanent deep tracks, use of hard faced approach roads and many other possible solutions.

As a general rule, watering points for cattle in tropical and subtropical regions should not be spaced wider than about 2 km apart. Water quality is an important aspect in good management and it should be tested.

7.4.3 Soil Conservation on Pasture Land

i. Description of pasture land

This class of land is generally used intensively through establishment of reseeded and high yielding pastures. Its most important features are relatively shallow soils (40-50 cm deep) with less than 30% gravel and slopes not exceeding 25-30%.

Very often, zero grazing (or stall feeding) is practised. The system may be supplemented by feeding forage crops grown on arable land.

Lands in this class may sometimes have been abandoned croplands, with shallow soils, steep slopes and suffering from erosion. Others may be existing range and natural forest where the soils are sufficiently deep and the slopes not too steep for conversion to good pasture land.

Occasionally abandoned terraces, and even fairly level land with insufficient soil depth for cultivation might be included in this class. The climatic factor is especially important and decisive in semi-arid and arid zones.

Socio-economic and infrastructural aspects also have to be considered, such as traditional systems and ways of life, communications, transport, markets and others.

ii. Treatment

The most important treatment is good land preparation (including the application of fertilizers and lime if needed) and reseeding with locally adapated mixtures of palatable and nutritious grasses, legumes and herbs.

Apart from fencing, brush control, and the provision of adequate water points, approach roads or trails, additional soil conservation practices may be required. They should include (see 7.3):

- Contour furrows, opened with a plough, at small horizontal distances, to retain and absorb the maximum amount of rainfall and to prevent runoff and erosion
- stone cordons: loose stones on the surface collected and deposited on contours
- silt traps, built from stone or soil in small depressions
- interception ditches, to prevent runoff from surrounding areas entering the improved pastures.

7.4.4 Soil Conservation on Range Land

i. Description of range lands

Most range lands are naturally established extensive grazing lands where natural reseeding takes place. They are poorer and less productive than pasture lands.

Soil depth may be down to 25 cm, with a higher gravel content and rock outcrops may comprise up to 50% of the total land. Slopes may also be as severe as 50%.

Erosion is likely to be moderate to severe and the vegetative cover of low density due to overgrazing and cutting of trees and bushes for fuel.

Unimproved lands of this type may often cover large areas and be one of the major causes of floods and sedimentation in the watersheds. These areas also often provide the major part of available communal grazing.

ii. Treatment

All activities required are as for pasture land but at lower intensity (fencing, rotational grazing, brush control, water points, furrows, rock cordons) but no ploughing and reseeding of the total area. The application of fertilizers and/or lime as necessary is also relevant.

Spot or strip seeding

This activity, which includes seeding of improved species of grasses and legumes adjusted to local conditions, covers only a small part of the total area. Depending on soil depth and stoniness, spot seeding may be done by manual labour. Strip seeding can be done on suitable sites by ploughing or disking strips for seedbed preparation. After the grass is well established it continues to spread by natural seeding and after a number of years should cover a large part of the area. The same work can be done by broadcasting the seeds and covering them by trampling with animals' hoofs.

Table 8 serves as an example for inputs for all improvements mentioned above.

Contour banks

In arid and semi-arid zones and on deep soils with gentle slopes, contour banks can be constructed at horizontal distances of 10-20 m. The runoff from the strips between the banks is stored along the banks and thereby greatly increases the water available to plants. Especially on soils with a high silt content (loess) sealing of the surface leads to high runoff even on narrow strips. For example on a slope of 2% water to a depth of 10 cm may cover a strip of up to 5 m in width along the bank and provide good growing conditions for the reseeded plants.

Water spreading

In semi-arid and arid zones rainfall is generally of short duration and high intensity. Water is diverted from the intermittent streams into a system of dikes which conduct the flood water, snake-like, over a wide area. Large plots can be irrigated by this system. The spacing between the dikes depends on the slope of the land, which would as a general rule be around 1%. On such slopes the dikes may be 30-40 m apart. A well constructed diversion weir has to be provided and the dikes must be protected against erosion at their bends by grass or, if possible, by stone paving.

The ratio between the spreading area to the catchment area varies greatly in different semi-arid and arid zones. The minimum ratio may be 1 (ha benefit area): 20 (ha catchment area).

Table 8. INPUTS[1/] REQUIRED FOR ESTABLISHMENT OF 1 HECTARE OF PERMANENT GRASSLAND

Grassland	Labour requirements (mandays) Construction 2/ m/d	Cultivation 3/ m/d	Total m/d	Draft cattle days	Seed kg	Lime T	Chemical fertilizers N kg	P kg	K kg	Chemical herbicide (2,4,D) kg	Supplied for 4/ fencing m fence
Reseeded pasture	60	10	70	15	30	4.5	100	170	200	1.0	170 (6 ha)
Overseeded range	20	10	30	8	20	4.5	100	100	150	1.0	100 (25 ha)

1/ Increased by 10% for technical contingencies.

2/ Labour for brush control and fencing.

3/ Labour for liming, fertilizing, and seeding.

4/ In brackets, total size of grassland area corresponding to the quoted length. In effect the length of fence per hectare depends on total size of grassland area. An electric fence unit (1 000 m line) may serve up to 25 ha of grassland for rotational grazing.

The diversion and inlet structures for water spreading should be very carefully prepared. Flash floods, especially in arid zones, can occur without prior warning and are caused by cloud-bursts in the higher mountainous areas. Consequently, all installations have to work automatically (without the assistance of human labour).

Sometimes waterspreading can be used for more intensive crops such as fruit tree plantations. In such cases, a number of inlets along the diversion canals should be provided to allow more even distribution of the water without having to move it through the whole system (starting from the highest, and only, inlet point). This possibility may be considered in areas where a number of floods can be expected every year.

7.4.5 Grass Establishment for Erosion Control

The stabilization of erodible soil on farm roadsides, canals, fish-pond banks and dam walls is very important for the long term maintenance of these structures. Stabilization is often attained by sodding, which is expensive, labour intensive and gives variable results. A cheaper, quicker alternative, giving more uniform results is grass seeding.

The procedure is to grade slopes evenly, apply fertilizers, rake to mix them with the soil, broadcast the seed and then firm the soil.

For successful establishment and growth of grass on poor eroded soils, a high basic application of NPK compound fertilizer (400-600 kg/ha) is required.

On steep banks, wire netting and straw and/or borrow pits (1 m x 30 cm) can be combined with seeding to stabilize the soil surface during the early stages of grass establishment.

After several years the native grasses should increasingly take over from the introduced grass, which by then will have served its purpose well.

7.5. SHELTERBELTS - WINDBREAKS

Shelterbelts are an important soil conservation practice improving the micro-climate for the production of crops, and the protection of crop and range lands against destructive wind erosion.

Shelterbelts are tree and bush plantations, planted at right angles to the prevailing wind direction. If the wind direction changes frequently a checker-board pattern of plantings is required. Otherwise only parallel lines are needed.

From 2-5 rows of fast growing trees of different heights should be planted to prevent any possible breaks in single rows, which would create a tunnelling action with high and dangerous wind velocities.

Windbreaks should be partly permeable to prevent turbulence. A permeability of 30-40% is considered the optimum.

The distance between shelterbelts should be about 20 times the expected height of the trees after 5-7 years of growth.

No cutting for firewood should be permitted in shelter-belts. For fruit tree plantations or other crops sensitive to damage by wind (banana) the distance between windbreaks should be reduced to 10-15 times their height.

6 SOIL AND WATER CONSERVATION AND FORESTRY

7.6.1 Description

The establishment of a forest cover under good management is by itself the most effective soil and water conservation component, more than any other practice discussed above. However, well established forests are in most cases only to be found in remote areas with very low population densities. Wherever rural communities exist, the forest tends to be damaged and often completely destroyed.

No slope groups can be established as limiting factors and soil depth would be difficult to describe, especially in rocky areas which may nevertheless have many pockets of deep soil suitable for planting trees.

The land must however have sufficient productive capacity for the establishment and support of the desired forest type, which differs according to climate, soil and slope conditions.

This land utilization group should include: industrial forests, natural forests with high production potential, fuel forests, fruit and fodder bearing forests, forests for agri-silviculture and some special groups which may be found, or are possible to establish, under specific local conditions.

In a watershed there may also be forest lands which have lost most of their productive capacity due to misuse and severe erosion. These lands are just one step ahead of the badlands. They should still have some potential for the establishment of a protective forest of trees and bushes with a low canopy. This serves only as a protective forest for the prevention of erosion, floods and siltation. No returns from cutting or grazing should be expected. All plants must be adapted to very poor soil and growing conditions.

Another type of protective forest is that of the uppermost mountainous parts of watersheds in humid tropical regions and the forest cover along torrents and rivulets. All these types of protective forest should be left undisturbed by man or livestock.

Forests can be established and/or maintained on practically all soils, slopes and under a wide range of climatic conditions. Sometimes even highly productive land could and should be used under this land utilization group for special circumstances which would give it a high priority, for example:

- the establishment of village fuel forests near the village
- a combination of forestry and agriculture (agri-silviculture) which could also be connected with forage production for animal feeding.

The establishment of a well managed and protective forest requires a number of activities to be carried out until the forest itself has developed its full conservation capacity.

7.6.2 Treatment

Re-afforestation is recommended where the existing cover of the forest land needs to be increased by complementary planting.

Afforestation is applied where no such cover exists and the whole area needs to be planted with trees. On lands with steep slopes and erodible soils, physical assistance for erosion control in the establishment stage may sometimes be required, by construction of basins and steps.

Total protection of the area by forest guards against grazing and cutting must be provided over many years.

Under a system of agri-silviculture where forage crops are produced, together with the establishment of the forest, only cutting of forage and feeding outside the area should be permitted. The removal of litter for burning or composting must be prevented.

Weeding, thinning and pruning are essential for the establishment of good stands. Sometimes application of fertilizers after planting is needed.

Fire breaks are necessary.

In production and industrial forests access roads and forest roads have to be constructed and maintained. In a protective forest, roads should be kept to a minimum and used only for vigilance purposes.

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Special consideration should be given to the rotational harvesting of fuel forests after a number of years of total protection.

Special treatment of gullies by diversion and interception ditches, gully plugs and silt traps may be necessary

7 SOIL CONSERVATION ON WASTELANDS

7.7.1 General

Wastelands are lands which in their present condition are unsuitable for any use. Most of them remain so even after large investments have been made mostly through manual labour, to stabilize them and prevent damage on agricultural lands caused by them.

Practically the only lands that could be reclaimed from this utilization group are swamps, which could be drained, and lands along meandering rivers which could be reclaimed by river training.

The most important are the eroded badlands which need special attention in comprehensive watershed development.

7.7.2 Eroded Wastelands

i. Description

These lands are synonymous with badlands and exhibit situations where degradation has reached a final stage. Badlands are irrevocably lost for any kind of agricultural and forestry production. They are the most important sources of sediments and erosion debris reaching the lower parts of the watershed.

These areas are generally located on the steep hillsides, formerly covered by forest and later cleared and cultivated, under a system of shifting cultivation. With the increase in population and pressure on the land they have been constantly cultivated without adequate soil conservation measures.

Most of these lands are on fairly steep to very steep slopes and probably should not have been cultivated at all. Rain-splash, sheet, rill and gully erosion have practically destroyed these lands. Gullies have crept uphill at increasing speed until finally the lands have been abandoned.

ii General aspects

A general observation should be made here. Whole hillsides which have been organized into small and sodded steps, channels and concrete drop structures may look impressive to the eye. However it should always be remembered that it is not important how good an improvement looks but only how well it works.

The guiding principle in erosion control on wastelands should be to make the most effective start at the lowest possible cost and to let nature take over and complete the healing process over a number of years. The area has to be absolutely protected from any cutting or grazing over a long period.

Mechanical and biological works have to be employed, but large scale and expensive engineering structures should be avoided as much as possible.

iii. Revegetation

Covering the bare and eroded lands with a protective vegetative cover should be the main objective of badland reclamation. This is however a difficult task, considering the extremely poor subsoil and/or parent material, the steep slopes and the sometimes deep gullies.

Extremely hardy native pioneer plant species can occasionally be found on badlands or can be introduced. Afforestation has little chance of success and only protective planting of shrubs adapted to the conditions could probably be found in most climatic regions. Grasses and legumes play the most important role in this regeneration effort. In most cases spot planting/seeding alone does not succeed and mechanical means have to be applied to encourage the germination of seeds and the establishment of planted shrubs.

Overlapping half-moon shaped small basins with a backslope are probably the most effective and cheapest method. The basins serve as mechanical silt traps and store runoff during the period of establishment. Fertilizers also have to be used to give the plants a better start. Under extremely difficult conditions, wire netting, sometimes over a layer of straw, will be necessary.

Once a start in establishing a plant cover has been successfully made, the grasses, legumes, herbs and shrubs propagate themselves, provided full protection is maintained. Small repairs of breaks in the traps must be made and a second application of fertilizer is recommended.

It is important to catch as much debris and water as possible to prevent them from reaching the gullies. Bunds and small basins can be used over the total eroded area. The mechanical silt traps can be reinforced by planting vegetation around the outer perimeter of the basins if suitable species can be found. Loose rocks and stones on the surface can be used for the same purpose.

The elaborate building of small steps on the contour with sodded risers or stone walls may be applied on selected areas, such as banks along highways, but it is extremely expensive and in fact less effective than the basin method. Too much loose soil is used in these small terraces and not enough space is allowed for trapping of eroding material. Once the small steps have been partly filled with debris, thereby giving them a downhill slope, they become useless and create severe gullying. This may happen during only one rainstorm.

iv. Gully Control

The first principle in gully control is to reduce as much as possible the amount of water running through them. Gully heads in particular have to be completely protected by interception ditches, which should spread the water over the area treated. Diversion ditches all along the gully walls at small intervals and in a herringbone pattern should further divert water from the gully sideslopes away from the gully walls and spread it over the same protected area.

If the gully is V-shaped, this can easily be done. On U-shaped gullies with straight walls, these ditches should start as close as possible to the upper edge of the vertical walls. Again, it is imperative that the whole area above and along the gullies be protected.

On the gully floors, gully plugs and silt traps should be used. Local materials found in the gully should be used as much as possible. Gabions may be one of the best uses of stone, both for the plugs and along the gully walls to prevent scouring. Live plant traps for strengthening the mechanical means should be used wherever possible.

Vertical gully heads and walls have to collapse and become V-shaped. By applying the above methods this happens gradually and the established vegetation on the area around the gully and on the gully floor stabilizes the eroded material.

The installation of sophisticated engineering structures should be avoided except in very special cases. It can be observed that a considerable number of such structures collapse after a very short time.

Special emphasis is again given to the basic principle that the only way for gully control is from the top, above the gully head and along its walls on both sides.

It should be left to nature to heal the wounds, with assistance as necessary to start the process, which may take many years to complete.

If a gully is not too deep and is located in an area where it interferes with cultivation, mechanical filling by machinery or manual labour can be considered. This solution can be applied in cases where the area is dissected by only one, or a small number of, gullies. The reclaimed gully has to be carefully protected from running water by interception ditches. This is also necessary where the filled-in gully is transformed into a grassed waterway. The interception ditch has to be maintained until a full and protective plantcover has been established. Only then can the former gully be put to its intended use as a grassed waterway.

7.7.3 Outwash Fans

Outwash fans occur where steep and deep gullies enter into more gently sloping land. The velocity of the runoff water and its carrying capacity are greatly reduced and the heavy material, mainly boulders, stones and gravel, are deposited at the outlets in a fan-like deposit, which may sometimes be many metres deep. To stop further extension of such areas the practices prescribed for gully control have to be applied in the gully itself. This gradually reduces and finally stops the material carried down from the gully.

The fan area itself cannot be expected to be returned to any productive use. The efforts made should be only to stabilize it by planting such shrubs, trees and grasses, which can establish themselves under the extremely poor growing conditions. No returns should be expected from these activities, but they are important in order to prevent damage on the agricultural land below.

7.7.4 Stone, Gravel and Sand Deposits

During heavy rainstorms, and floods arising from unprotected uplands, large amounts of stone, gravel and sand may be carried downstream from eroding areas and active gullies. This heavy material is deposited on the lower lands with gentler slopes, where floodwaters loose their velocity and some of their carrying capacity.

i. Deposits in river channels

Riverbeds are the most common location for such deposits. In riverbeds water velocity is generally fairly high, even on gentle slopes, because of the limited cross-section. Consequently, only the heaviest particles are deposited there, such as stones, gravel and coarse sand. Further downstream on gentler slopes and wider riverbeds, fine sand and even some clay and silt particles may be deposited. However, the general effect of all these deposits is to raise the level of the riverbed.

The practice of protecting the surrouding land by levees and stone and sand traps can be considered as a temporary solution only. In fact, there are many regions where the river bottom is higher than the surrounding land protected by levees, because the bottom has been raised gradually as more eroded material has been deposited in the river channel. This is very dangerous in flat lowlands with their productive soils. In sudden flash floods these levees can be finally overtopped and destroyed, and then disasterous flooding occurs on valuable cropland, villages and towns.

The construction of levees along river channels in the lowlands is certainly a worthwhile investment, but only if the sources from which the floods and deposits come can be properly controlled. This can only be achieved by treating the mountainous and steep uplands with all the soil conservation practices discussed above.

When these areas are properly treated and protected the occurances of flash floods and heavy bedloads are radically reduced and levees on the lowlands, on a much reduced scale, may be a long term solution for protecting agricultural lowlands. It has to be clearly understood that there are just no short term solutions to this problem.

In general, experience has shown that after devastating floods, governments are ready to decide on quick and expensive action, mostly of an engineering nature, without practical consideration as to treatment of the evil at its source. The results of such activities are consequently only of a temporary nature and floods occur again and again. (Channel improvement - river training is discussed in more detail in Chapter 8).

ii. Deposits on agricultural lands

When flood water spreads over wide areas, its velocity and carrying capacity is considerably reduced and large amounts of eroded materials are deposited on the productive agricultural land. This kind of calamity often destroys not only crops and livestock but also causes heavy losses to property and human life.

The only long-term solutions are discussed in section 7.7.4 (i).

The only practical solution to the deposits on agricultural lands, is to remove the layers of unproductive deposits and if possible to incorporate the silt and clay layers into the land by ploughing.

7.7.5 Landslides

Landslides occur as a natural phenomenon in geologically unstable areas, but they may also be man-induced. This manual deals only with the latter case. They occur on steep slopes and on soils overlaying impervious subsoil or parent material, in most cases with a downhill slope. Landslides are always connected with a high moisture content of the unstable soils. The basic reason for such man-induced landslides is disruption of the ecological balance in the area. For example, deforestation may completely change the water balance in a soil profile and also remove the mechanical barriers of the roots anchoring the soil in place.

A knowledge of such unstable areas and the re-establishment of the ecological equilibrium are probably the only long term solutions for the prevention of landslides. This involves in almost all cases re-afforestation of the drainage basin of the area under treatment and the gradual revegetation of the area directly damaged by the landslide.

As a temporary physical support to the biological recovery process, deep interception and diversion ditches can be excavated around the drainage basin of the unstable soils to stop seepage reaching the area under treatment.

7.7.6 Sand Dune Fixation

There are two types of sand dunes: coastal dunes, and inland dunes. In the framework of watershed development the inland dunes and their fixation are of major concern. They are to be found in the arid deserts and the semi-arid zones. In the semi-arid zones they are often man-made, by cultivating or overgrazing unstable soils without any protective plant cover, thus exposing them to the selective forces of wind erosion. By this process only the heavy and coarse particles of sand are left behind, after the clay and silt have been blown away, sometimes over very long distances.

Sand dune fixation is a unique sector of soil conservation with specific techniques, due to the difficult conditions, instability of the soil, the abrasive action of the sand grains and the low or practically non-availability of plant nutrients. The final target of sand dune fixation is however identical to most other soil conservation practices on uncultivated land - to create a permanent and dense plant cover.

The practices for sand dune fixation are dealt with in specialized literature. In this manual only very general guidelines are given.

The first and most important step in sand dune fixation is complete protection from grazing or any other activity which may interfere with the re-establishment of vegetation of any kind. In semi-arid zones such protection may sometimes be sufficient to stabilize the dunes by natural recovery. This may however take many generations.

Mechanical barriers for protecting the establishment of plants are required in most locations. This may be done by low fences, made of dry reeds, mulching with vegetation wastes or by spraying with chemicals which are permeable to rain and germinating seeds, but create a firm film on the surface which prevents the shifting of sand grains. This has to be accompanied by seeding of grasses and the planting of bushes and trees which are adjusted to the low fertility level, the mechanical abrasion of moving sand and the low water availability, which is often accompanied by extended hot and dry periods. A combination of a few of the above methods are generally applied. This creates the conditions for the establishment of pioneer plants which gradually cover the total area by self propagation. This process takes many years, even under the best climatic conditions.

Complete protection has to be provided, even after fixation by vegetative cover. Even slight disturbances, such as the creation of footpaths or wheel tracks may start new sand movement.

There are conditions where sand dune fixation on large desert areas cannot be carried out with any hope of success. Under such conditions all possible conservation activities should be on the border area, between the desert dunes and existing or potential agricultural lands, to stop the encroachment of active dunes onto the productive lands.

7.7.7 Swamps

Three main kinds of swamps can be distinguished: sweet water swamps, brackish water swamps, and saline swamps.

These swamps are wastelands which cannot be used throughout the year for agricultural production. They may be depressions without any outlet and which are permanently flooded, or areas with a water table up to the soil surface, or permanently flooded due to seepage from surrounding higher lands.

Such lands are to be found in the lowlands, but may sometimes also occur in depressions on highlands and on slopes where seepage causes the swampy conditions. Drainage of such swamps is a subject for hydrologists and engineers. However, general guidelines are given below.

In most cases sweet water swamps can be drained and converted to agricultural use. Swamps with brackish water can sometimes also be considered for reclamation for special purposes, such as lowering the water table and establishment of date palm plantations, or for the production of special reeds.

Salty swamps can generally only serve as protected wildlife habitats.

Swamps located in depressions without a sufficiently low outlet, or swamps created by a high groundwater level can be reclaimed by cutting through the barrier and by opening canals to remove the stagnant or surplus water. In swamps with a high water table a network of open canals and/or underground drainage pipes would collect and discharge all surplus water.

It is important to know in advance to what use the reclaimed area is to be put. This determines the depth of canals and drainage pipes. For example for intensive pastures a groundwater level of 20-40 cm below the soil surface may be the optimum. For most annual field crops not less than 50 cm soil above the groundwater level will be required, and for most fruit tree plantations depths of more than 1 m will be necessary. Generally a combination of open primary and secondary canals and underground drainage pipes is likely to be the best solution, except where high water tables are beneficial for the crops to be grown on the land.

A very special group comprises the peat swamps which have a high production capability, but require very special safeguards in the form of drainage works to prevent damage caused by fire and wind erosion. The main precautions to be taken in their drainage would be the ability to regulate the groundwater level, which would also serve as a means of providing underground irrigation, and to keep the surface always sufficiently wet to prevent wind erosion. Generally, a fairly high water table should be maintained in reclaimed peat swamps and they should primarily be used for the production of annual crops or intensive pasture. Fruit tree plantations should not be established on such lands because of the high and variable water table which would exclude this type of land use.

Where seepage causes the swampy conditions, deep cut-off ditches and/or drainage pipes would remove the seepage water to safe outlets.

On the whole swamps are the wastelands with the highest potential for reclamation and sometimes they can be put to very intensive use. This is important considering the high investment required to reclaim such lands.

REFERENCES

FAO 1967 Working papers of project AGL/ROK/67/522

FAO 1976 Conservation in arid and semi-arid zones. Conservation guide No.3.

FAO 1977 Soil conservation and management. Soils bulletin No 33.

FAO 1977 Guidelines for the development of less favourable areas. A comprehensive integrated watershed development approach.AGS/MISC/77/2

FAO 1977 Guidelines for watershed management. Conservation guide No.1.

FAO Manual for development planners (in preparation).

Food and Agriculture Organization of the United Nations (FAO). 1965. Types of erosion damage. In Soil erosion by water: Some measures for its control on cultivated lands. Rome: FAO.

Geologic and accelerated erosion

There are two major types of erosion, namely, geologic and accelerated. They represent contrasting types of soil removal. Failure to distinguish between them has contributed to indifference with respect to recognizing the seriousness of erosion damage and the importance of soil conservation programs.

In its broadest sense geologic erosion is a normal process, representing erosion of land in its natural environment without the influence of man. Accelerated erosion is in excess of geologic erosion and is induced by man's activities which have brought about changes in natural cover and soil conditions.

Geologic erosion has been going on since the time continents emerged from the sea. It is caused mainly by the action of water, wind, temperature variations, gravity and glaciers. It has been responsible for the wearing away of hills and mountains and the cause of present land surface features, such as sculptured hills and mountains, canyons, plains, deltas and stream channels.

Geologic erosion includes soil-forming as well as eroding processes. The rate of this erosion, combined with the complex processes of soil formation, largely determines the kind of soil that has developed and its distribution on the earth's surface.

Accelerated erosion results from man's activities when preparing land for the production of food and fiber and as a place to build homes, industrial plants and transport facilities. In this way, he has an opportunity to exercise control over its occurrence. Unless measures are taken to guard against destructive erosion it becomes the most potent single factor contributing to deterioration of productive soil.

The action of water and wind are the primary causes of accelerated erosion. Only water erosion is dealt with in this book.[1]

[1] See *Soil erosion by wind and measures for its control on agricultural lands*, FAO Agricultural Development Paper No. 71, for a discussion of soil erosion by wind.

Gullying

Gully erosion is channel erosion that cuts so deeply into the soil that the ground cannot be smoothed out by ordinary tillage tools. It often follows sheet and rill erosion. It occurs, either where runoff from a slope increases sufficiently in volume or velocity to cut deep incisions, or where the concentrated water flows long enough in the same channel to develop deep incisions. Gullies may develop from rills which are allowed to go unchecked. Often, they develop in natural depressions of the land surface where runoff water accumulates. Gullies are often started by ruts or tracks made up and down hill by the movement of machinery or livestock.

The rate and extent of gully development is closely related to the amount and velocity of runoff water. Gully development depends on relatively

large quantities of water to supply energy for both detaching and transporting the soil. The amount of water available is closely related to the size and runoff-producing characteristics of the drainage areas involved. The rate of gully erosion is further conditioned by the soil characteristics, size and shape of the gully and the slope in the channel.

How gullies develop

Gullies are known to develop by several processes which may occur singly or at the same time. These processes are:

1. Scouring in the bottom or on the sides of the gully by flowing water plus any abrasive material, such as soil particles or debris carried by the water.
2. Waterfall erosion at the gully head which causes cutting back into nongullied land.
3. Slides or mass movement of soil into the gully from the sides, caused by the lubricating action of seepage, alternate freezing and thawing or undercutting by channel flow.

There is a wide range in size depending on where the gullies are located, their age and the many conditions contributing to their development. They may be narrow and only 2 or 3 feet deep, or they may range to enormous size — 30 to 40 feet deep and 75 to 100 feet wide, such as in the deep loess soil area of western Iowa (U.S.A.), or to an even greater size such as found in the southern Piedmont region of the United States and other areas.

The cross sections of gullies frequently assume a V or U shape. The V-shaped form often occurs where the subsoil is resistant to rapid cutting because of fine soil texture or toughness (Figure 18).

The U-shaped gullies are often found in loessial regions and alluvial valleys where both the surface soil and subsoil are easily eroded. Under such conditions the channel flow undermines and collapses the gully banks resulting in vertical side walls and a U-shaped cross section. It is not uncommon to find both V and U shapes in the same channel.

Gully control

Gullying is an advanced stage of erosion and a very costly one. Much land can be destroyed by the gully area itself. Other land loses value when it is dissected by gullies, often making small, odd-shaped fields and

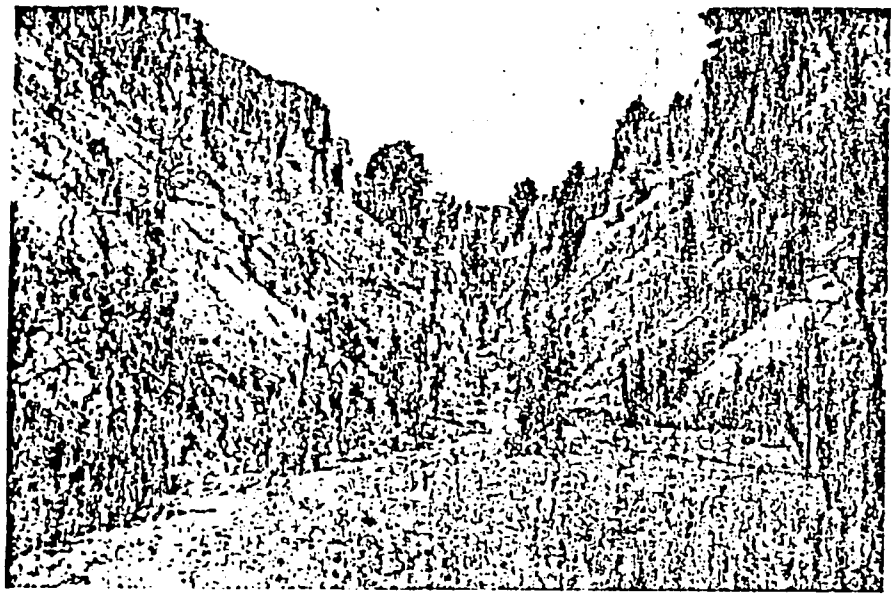


FIGURE 18. A large V-shaped gully in South Carolina.
(Photo by Clemson College, Clemson, S.C., U.S.A.)

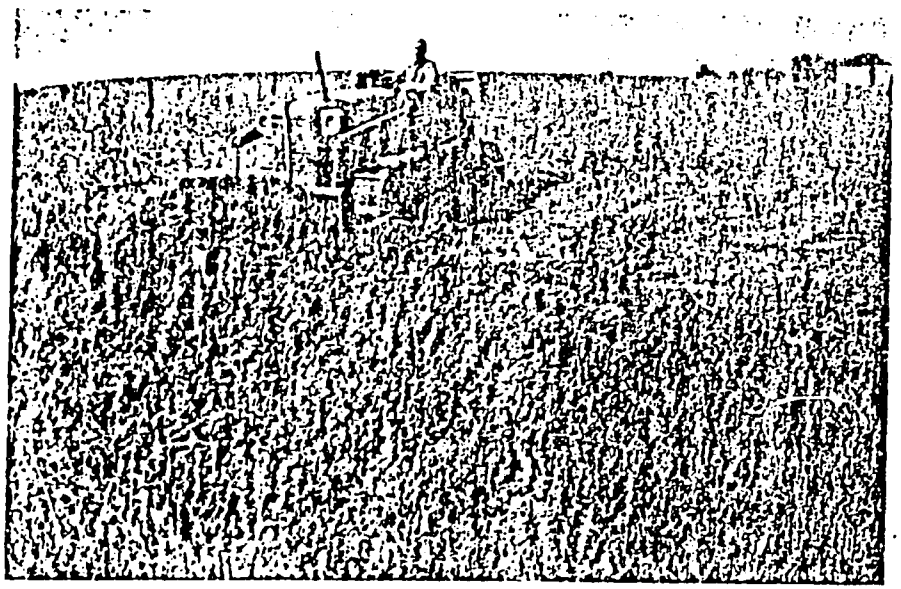


FIGURE 19. Repairing gullies is often costly. Here, soil is being pushed into the gully prior to shaping and seeding a grassed waterway.
(Photo by Iowa State University, U.S.A.)

restricting free movement of farm machinery. The repair and stabilizing of existing gullies is the most costly of all erosion control endeavors. It may require extensive earth moving and the building of dams or other structures (Figure 19). Gullying can usually be prevented through good land use, and attention to suitable cropping systems and soil/water conservation measures. For more details on control see Chapter 4.

Sedimentation

THE SEDIMENTATION PROCESS

Soil that is eroded from its original location is always deposited somewhere else. This may be close to its place of origin; it may make the longest possible journey and come to rest in the sea, or it may settle out at any point between these two extremes.

The distance eroded soil particles travel depends primarily on their size, density and shape and the velocity of the runoff water. Coarse sand particles in eroded soil move the shortest distance and settle out first (Figure 20). Fine sand and silt drop out next as runoff water slows down. Some very fine silts will settle out only in standing water. Very fine clay and colloidal humus will not settle out even in still water but stay suspended indefinitely. They are so small in size and finely dispersed that they assume a colloidal nature (they are kept in suspension by the molecular motion of the water). Clay and humus particles remain in suspension until coagulated by a specific concentration of electrolytes (usually salts) in the water, or until precipitated by a sharp drop in temperature, especially freezing to ice. Whenever clay or humus suspensions reach the ocean with its salt concentration the particles coagulate and soon settle out. Sometimes coagulation is induced by adding salts, such as calcium chloride, to ponds or small lakes in order to clarify turbid water.

LOCAL DEPOSITION

The bulk of eroded material from hillsides comes to rest at the foot of slopes or on nearby flood plains (Figure 21). This material is, primarily, a result of sheet and microchannel erosion. The material has moved a relatively short distance from the fields from which it eroded. It was deposited when the flowing water slowed down as the topography began

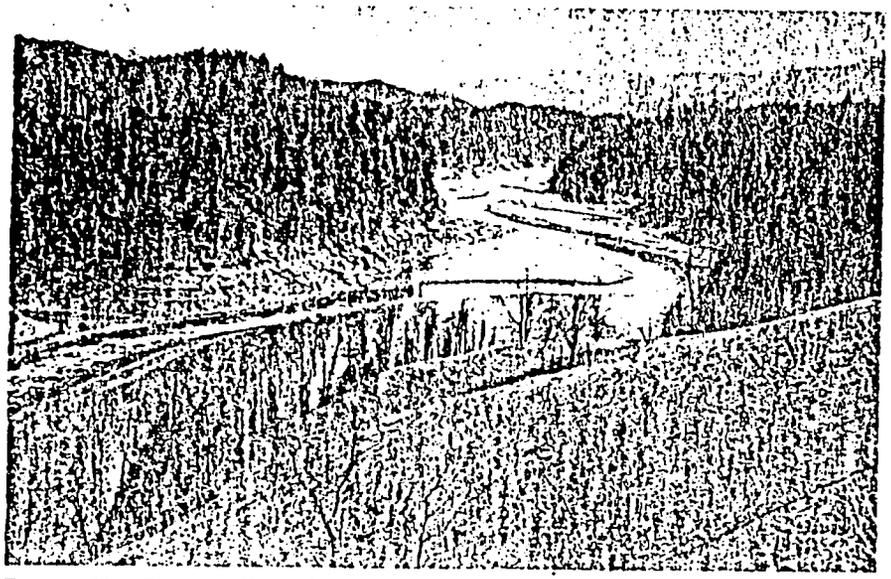


FIGURE 20. Coarse soil particles have settled out in this stream which is entering a storage reservoir.

(Photo by U.S. Department of Agriculture, Soil Conservation Service)

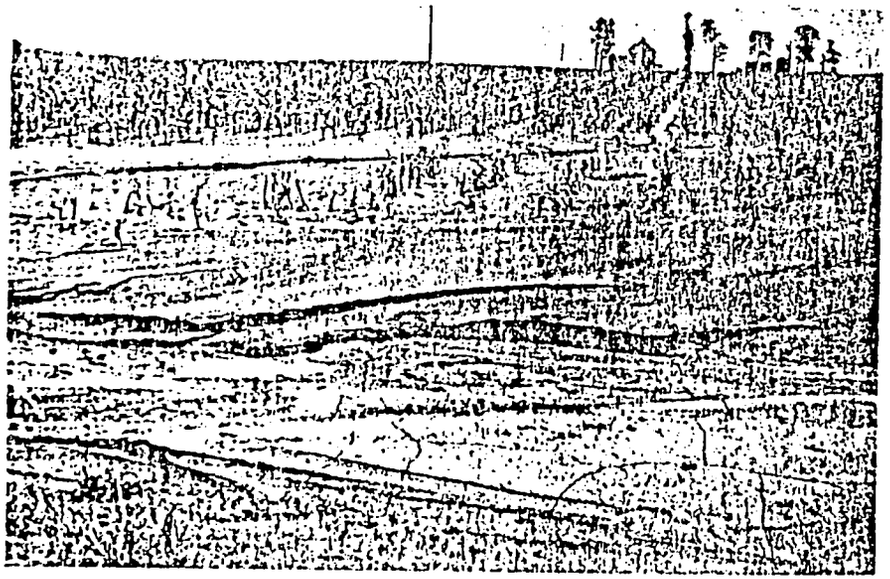


FIGURE 21. The bulk of eroded material comes to rest at the foot of slopes or on nearby flood plains.

(Photo by U.S. Department of Agriculture, Soil Conservation Service)

to flatten out. These deposits tend to be somewhat finer textured, and higher in organic matter, than the original soil because of the sorting action of the erosion process.

Some of the eroded material from sloping fields may find its way into large rills, gullies or small local tributary streams and be carried further. Eventually much of it may be deposited as small alluvial fans when these channels undergo abrupt changes in gradient. Some may settle out in small local bottomland areas when the flooding water spreads out and decreases in volume and velocity. Some may be deposited in local drainage and irrigation ditches or in small local reservoirs constructed for stock water or recreational purposes.

Much of the damage caused by local sediment deposits results from this silting-in of farm waterways, drainage ditches and water reservoirs. Other damage is caused by the burying of growing crops and by decreases in the productivity of fertile bottomlands. Control measures will be concerned primarily with the prevention of erosion on the sloping uplands. Adjustments in land use and cropping systems may be necessary (Figure 22).

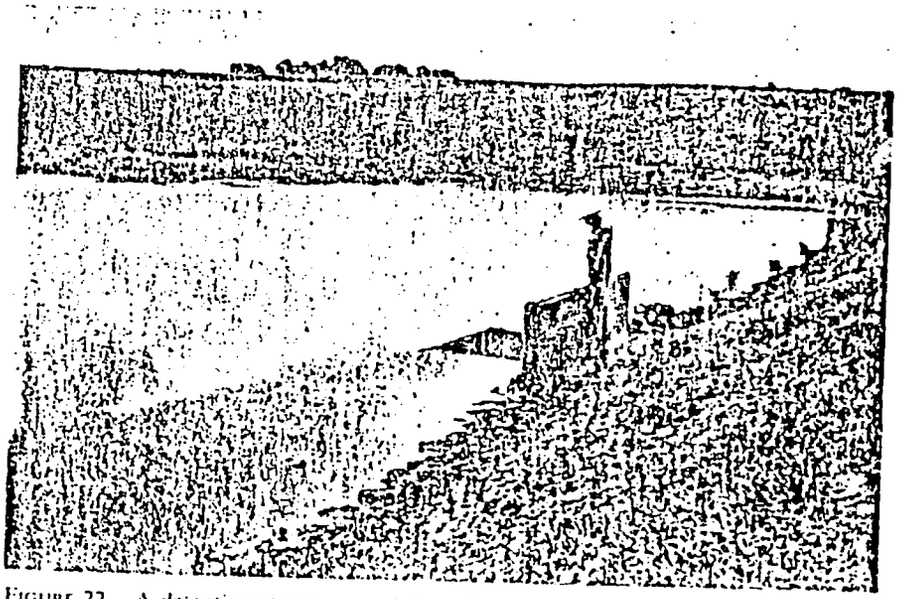


FIGURE 22. A detention structure used for gully control and flood prevention in Iowa. Conservation practices in the watershed above the reservoir are necessary to maintain its capacity and usefulness.

(Photo by Iowa State University, U.S.A.)

Also, greater use of practices such as contouring, terracing, strip-cropping and well-designed waterways may be required.

Downstream deposition

The deposition of eroded soil in localized areas — areas within an eroding field or in an adjacent one or in bottomland areas of a relatively small watershed — is the kind of sedimentation that is immediately evident and of concern to the farmer. He observes that costly damage is being done to his crops, his land, and facilities, such as waterways, drainage ditches and ponds. But sedimentation and subsequent damage also occur downstream, often great distances from the source of eroding uplands. Sedimentation of this kind is usually not as well recognized by those who farm the land. But it is often of great concern to those who live and work along large tributaries or in the valleys of major streams.

The amount of sediment carried out of small watersheds into major streams can vary widely. It is dependent upon the size of the drainage area, the amount and character of runoff, topography of the watershed, the extent of channel development and other factors which determine the ability of the stream system to pick up and carry sediment. It is estimated that in large, gently sloping watersheds, less than one fourth of the material eroded in such watersheds is carried out. On the other hand, in small, steeply sloping, highly channelized watersheds one half or more of the eroded material may find its way into major streams.

Once sediment reaches a stream, it is transported in two ways: (*a*) as suspended load, and (*b*) as bed load. Suspended load is distributed throughout the cross section of stream flow. It consists primarily of clays and colloids. Silts may also be distributed throughout the cross section in turbulent flow and tend to increase in concentration with depth of flow. These fine materials can stay in suspension in flowing water for long periods and can be carried great distances.

Bed load is made up of coarse materials such as sand, gravel, cobbles and small boulders. It is called bed load because it slides, rolls and bounces along the bed of the stream. It is in constant contact with the stream bed and is pushed along the bottom by the force of the water.

The nature of material transported is largely determined by the sources of sediment. If the main source is from sheet erosion, the material will

be fine textured and move as suspended load. In places where channel erosion is great, the sediment is likely to be coarse-grained and is transported as bed load. Measurements of sediment loads in streams of the U.S. Midwest indicate that often 90 percent or more of the sediment is transported as suspended load.

There appears to be a relationship between the sediment load of a stream and stability of the channel. Suspended material travels with the same velocity as the flow and is seldom present in quantities greater than the flow can carry. Consequently, it is seldom deposited in the main channel and has only a minor part in channel stability.

But bed load is always in balance with flow conditions and markedly influences the stability of channels. If bed material overloads the flow, deposition occurs. If the load is less than can be carried, the flow will pick up extra material by attacking the channel walls in an effort to maintain a balance.

Damage caused by downstream deposition

The major damage caused by downstream sedimentation can be placed in three broad categories: (*a*) channel sedimentation, (*b*) filling of reservoirs, and (*c*) sedimentation on bottomlands.

Channel sedimentation occurs where the coarser parts of stream-borne material accumulate faster than the stream can move it. Such deposits tend to accumulate mainly in those places where the velocity of flow is decreased for any reason. Channel deposits often occur above the heads of deltas or at the lower end of relatively steep tributaries that enter a larger stream of significantly lower gradient. Accumulations at these locations reduce channel capacity and contribute to overflow and flooding of adjacent lands. It may increase drainage problems of adjacent bottomland by raising water table levels and by causing swamping. Swamping is the trapping of water behind natural levees along stream channels which develop from deposition caused by stream overflow.

The filling of drainage canals and ditches is a serious form of channel sedimentation in many localities. Channel sedimentation can be a serious problem in navigable rivers. For example, the upper Mississippi river channel receives eroded material from tributaries at a faster rate than can be removed by the Mississippi. Consequently, large sums are spent annually on dredging to keep the channel open for barge traffic.

Filling of reservoirs

Reservoirs are frequently placed in the path of rivers or streams. The still waters of the reservoir cause a part of the soil, carried by the stream, to drop out. Coarse sands and gravel are either dropped out before the stream enters the reservoir or at the entrance to it. Consequently, most of the sediment found in reservoirs consists of fine sand, silt and some clay and organic matter. Silt commonly makes up half or more of the sediment (Figure 23).

Deposition in all types of reservoirs reduces the water storage capacity and shortens their useful life. This reduces their value since reservoirs are constructed to store water for purposes such as municipal water supply, industrial use, power, irrigation, recreation or flood control. If the water is to be used by municipalities or by a manufacturing plant, concentrations of sediment add to the water cost because of the need for filtration. Most reservoirs are designed for a 50-year life span at least and allowances are made for siltation. Thus, siltation adds to the structural costs, especially if a high rate is anticipated.

The rate at which reservoirs fill with sediment depends on a number of factors, most of which are related to the contributing watershed. They include kind of soil and erodibility, topography or lay of the land, climate, land use or type of agriculture, and the ratio between the size of the watershed and the volume of the reservoir. Although some silting will always occur in reservoirs, man has control over some of the contributing factors and can do much to control the rate of filling. Some reservoirs have been known to fill up completely in a few years because of poor land use and mismanagement in the contributing watershed. In other cases, reservoirs in comparable locations are known to have slow rates of siltation because of proper land use combined with good soil management and use of conservation practices.

Sedimentation on bottomlands

Sedimentation on bottomlands caused by overtopping of streams can be both harmful and beneficial (Figure 24). As already mentioned, if flood waters deposit silt in works of improvement, such as reservoirs, drainage ditches and irrigation channels, damage is done. Furthermore, if flooding streams deposit large amounts of coarse material or material of low fertility over fertile agricultural land, obvious damage is the result.

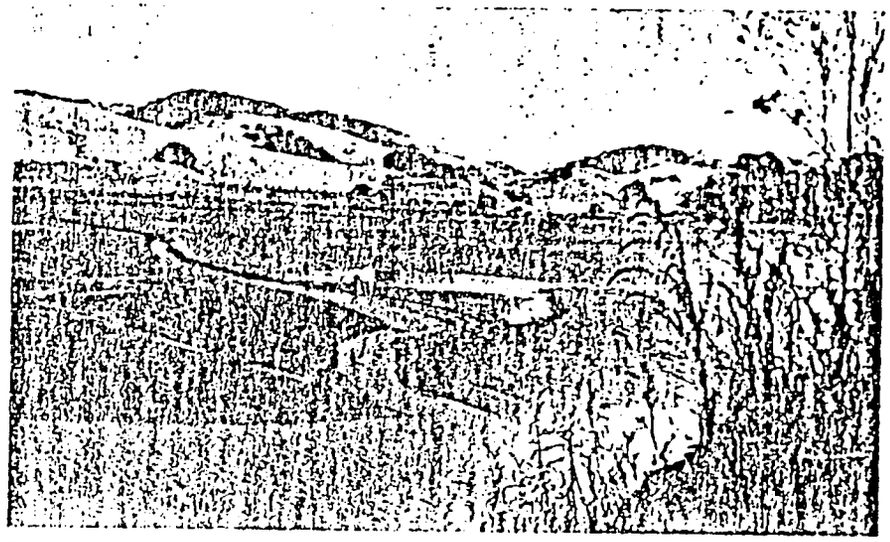


Figure 23. Large amounts of silt have been deposited at the upper end of this reservoir in California.

(Photo by U.S. Department of Agriculture, Soil Conservation Service)

Figure 24. A flooding stream deposited silt on this bottomland, seriously damaging the maize crop.

(Photo by U.S. Department of Agriculture, Soil Conservation Service)

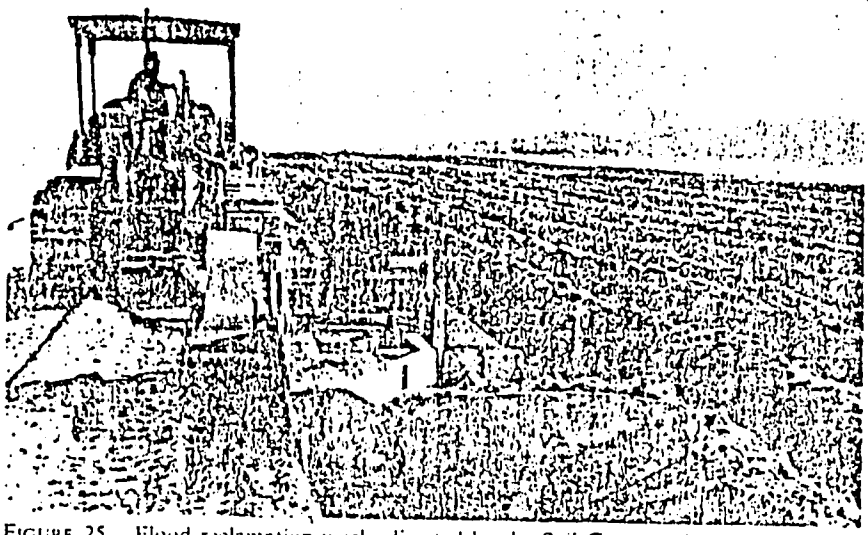


FIGURE 25. Flood reclamation work, directed by the Soil Conservation Service during 1958/59, on the Arkansas river bottomlands. Deep plowing turns under sand and sediment deposited by a flood.

(Photo by U.S. Department of Agriculture, Soil Conservation Service)

It is not uncommon for large flooding streams to deposit deep layers of sand over productive bottomland. In some cases such land is lost to production and in others great sums of money have been spent in operating large plows and other equipment to plow under the sand or mix it with the underlying surface soil.

If soil material that is deposited is of suitable texture and contains fertile material it can improve the productivity of the land. If the land is being farmed already, the sediment must be deposited at the right time or slowly enough so that it does not interfere with the usual farming operations.

Floods often deposit large quantities of unfertile material over good farm land. Deep plowing offers a means of reclaiming the land (Figure 25).

Sometimes poor land is improved or actually brought into production by controlled sedimentation. This is done by constructing a dike around the area in question and diverting silt-laden water into the basin formed by the dikes. The water spreads out in the basin and drops its load of silt. Provisions are made for drainage of surplus water. Such structures are called "desilting basins." They have been used successfully in a number of areas. A 312-acre desilting basin in western Iowa trapped runoff water from Pony Creek. In about 20 years the once unproductive area has been covered with 3 to 9 feet of silt and is now excellent farmland.

El-Swaify, S.A.; E.W. Dangler and C.L. Armstrong.1979. Predictability parameters for rainfall erosion in the tropics. In Soil erosion by water in the tropics: A state of the art. Washington, D.C.: United States Agency for International Development.

CHAPTER 4
PREDICTABILITY PARAMETERS FOR RAINFALL EROSION IN THE TROPICS

Conditions that give rise to soil erosion by water have been the subject of many qualitative studies (see chap. 2). However, quantitative predictions based on the roles of individual causative parameters have generally originated and been verified in temperate regions, particularly in the eastern United States (Wischmeier and Smith 1978). While such predictions are possible for certain forms of erosion in locations where individual predictive components have been established, they present definite limitations when their use is extended beyond the original locale (Wischmeier 1976*b*). It is therefore instructive to provide both a qualitative account of conditions that generally enhance soil erosion and an assessment of the success of quantitative predictions of rainfall erosion in the tropics. By necessity, much of the information included in both sections was not obtained in the tropics. Fortunately, the principles that underlie the roles of the different causative factors are universally applicable.

CONDITIONS FAVORING HIGH RATES OF SOIL LOSS IN THE TROPICS

It has long been realized that for water erosion to take place, two distinct processes must be set in motion. First is the action (kinetic energy) of water (rainfall and possibly runoff) to separate detachable particles from the soil mass. Second is the transport (by runoff and possibly rainfall) of detached particles from their point of origin to a new destination. It is clear therefore, that the most important causes of water erosion are the characteristics of rainfall, soil, and physical setting of the land. The rainfall must be of sufficient intensity and duration to cause detachment and produce runoff (that is, exceed the soil's infiltration rate). The soil must be susceptible to particle or aggregate detachment and topography must have sufficient slope steepness and length to allow particle migration with runoff. These basic requirements are clearly modified by the absence, presence, and nature of vegetal cover as well as prevailing cultural practices such as land shaping or tillage.

The following is a list, developed from several sources (particularly ARS 1975), of the general conditions that lead to high rates of soil loss by water erosion:

1. High intensity and long duration of rainfall
2. High rates of overland flow from adjacent uplands
3. Poorly structured soils with low infiltration rates
4. Soils that lack coherence between top and subsurface layers (e.g. loose land fill or soils piled during construction activity)
5. Slopes with high or moderate steepness
6. Long slopes
7. Tillage and/or planting in rows directed with, rather than across, prevailing slope
8. Absent or sparse vegetative cover, with insufficient protective organic residue

Historically, though perhaps not always intentionally, humans have devised a variety of practices that reduce erosional losses by exploiting those parameters that lend themselves to management. Thus, when there was a choice, steep slopes were terraced to reduce the steepness and length of slope and to curtail loss of water by runoff, simultaneous clearing of massive areas of forest was avoided; and shifting cultivation was practiced whenever crops provided poor stands inadequate for soil protection. As emphasized earlier, tropical populations have only recently begun to deviate from well-established, wise uses of land resources because of increased population densities and accompanying needs for food and energy. These pressures exemplify socioeconomic factors that are themselves an "erosion determining parameter" which reaches beyond the physical factors responsible for the actual erosion process.

QUANTITATIVE PARAMETERS FOR PREDICTING RAINFALL EROSION IN THE TROPICS

Equations commonly used for predicting soil loss and prescribing erosion control measures were developed primarily in the Corn Belt (Midwest) of the United States. Historical review of steps leading to their development were given by Wischmeier and Smith (1978), Mitchell and Bubenzer (1980), and Muldenhauer and Foster (1981). First, a relationship between soil loss and slope length and steepness was developed by Zingg (1940). Crop cover and conservation practice parameters were added the following year by Smith (1941). In 1946 the Musgrave equation emerged, with the addition of a rainfall parameter (Musgrave 1947). Based on data from over twenty-five years' research, from which the rainfall parameter was modified and the soil susceptibility to erosion (erodibility factor) quantified, the universal soil loss equation (USLE) for predicting sheet and rill erosion was proposed (Wischmeier and Smith 1961, 1965). This equation is now the most widely used model for predicting sheet (interrill) and rill erosion (Wischmeier and Smith 1978). It has the form

$$A = RKLSCP \qquad (1)$$

and identifies six parameters (factors) as most influential in rill and interrill soil erosion by water: rainfall erosivity (R), soil erodibility (K), cropping-management (C), erosion control practice (P), and two topographic factors—length of slope (L), and steepness of slope (S). The authors quantified all parameters as "mean annual values" based on statistical analysis of voluminous soil loss data gathered from cropland erosion research stations east of the Rocky Mountains (Wischmeier and Smith 1965). Thus the R (rainfall) factor was defined as the number of erosion-index units associated with a normal year's rain; K as the soil's erosion rate per unit of rainfall erosion-index under unit values of the four remaining factors; L as the ratio of soil loss from the given slope length to that from a standard length of 22.13 m (72.6 ft) on the same soil type and slope gradient; S as a ratio of soil loss from the prevailing field slope gradient to that from a standard 9 percent slope; C as a ratio of soil loss from a field with specified cropping management and cover history to that from a comparable field in fallow condition; and P as a ratio of soil loss from contoured, strip-cropped, or terraced land to that from land under straight row cultivation up-and-down the slope.

The USLE is universal only insofar as it identifies all the parameters that determine the magnitude of soil loss due to rill and interrill (sheet) erosion. It is not useful, nor was it intended, for estimating losses caused by other forms, such as gully erosion (chap. 1). The equation has been used successfully by soil conservation planners in many parts of the United States for nearly two decades. Unfortunately, perhaps because of its name, it has also been misused widely within and outside this country. The developer of the equation recently expressed concern over this matter and reiterated the capabilities and limitations of the equation (Wischmeier 1976*b*). As discussed by other authors (Hudson 1971, El-Swaify and Dangler 1977; Lal 1977*a*), he stated that applying the equation in a new area (such as the tropics) without changing its component values is a misuse. So are applications for predicting soil losses from individual storm events or even specific years rather than from a long-term mean-annual basis, or for estimating sediment yields (e.g. from watershed delivery outlets) rather than erosion losses from original positions at specific field sites. Current research efforts aim to establish an equation that will be capable of estimating soil losses from individual storms, which (as stated above) is a function not intended for the USLE (Foster et al. 1977*a*,*b*). It is instructive to note here other potential errors associated with the use of the USLE as recommended by Wischmeier and Smith (1965, 1978). The following list is directly quoted from Wischmeier (1976*b*).

> Evaluating the [equation's] factors on too broad a base, such as a single C value for all cropland or all corn land.
>
> Applying C and P values from the handbook [USDA 282] indiscriminately without considering length limits beyond which the practices become ineffective. When a practice breaks down from too much accumulation of runoff, the effective C or P value increases rapidly.
>
> Extrapolating factor relationships far beyond the range of the data from which they were derived. This hazard, always speculative, applies primarily to L and S.
>
> Until research can expand the data, extrapolations of the formulas provide the best information available, but their limitations must be recognized.

Defining slope length incorrectly. The effective slope length is the distance from the point of origin of overland flow to the point where either the slope decreases enough that deposition begins or the runoff water enters a well-defined channel. Thus, a slope length is measured to a well-defined channel and does not include the length of the channel. Neither is a slope length terminated by a pronounced change in gradient or land use unless the runoff is diverted.

Evaluating irregular slopes. The slope-effect chart [in the Handbook] reflects relationships for uniform gradients. A convex slope loses more soil than an equivalent uniform slope, and a concave slope loses less. It is logical and correct to divide appreciably irregular slopes into relatively uniform segments for evaluation, but the segments cannot be treated as independent slopes if one segment receives runoff from another. A method of computing LS for irregular slopes was published [Foster and Wischmeier 1974].

In some earlier publications, factor R, unfortunately, was categorically equated with the local EI value. R should be defined as the rainfall and runoff erosivity. EI generally reflects this combination, but there are two exceptions. First, EI does not reflect the erosive potential of runoff that is not directly associated with rainfall. In the Palouse region of the Northwest, probably 90 percent of the erosion is caused by runoff from thaw and snowmelt. The erosive potential of this runoff must be added to the local EI value to evaluate R. Second, on the Southeast Coastal Plains, computed annual EI values are very high because of the hurricane-associated storms and the slope gradients are quite small. Field observers have suggested that the normally computed EI values seem to overestimate soil loss for this condition. A logical assumption is that this is largely attributable to shielding of the soil surface by excessive ponding of rainfall during the prolonged periods of high intensities. But further study is needed to determine the variables and interactions responsible for the apparent overestimation.

Because it has been applied successfully on the U.S. mainland, the USLE has also received some use in other parts of the world, including tropical regions (Roose 1977a; Hurni 1981). However, the equation has yet to be fully tested for applicability in these regions. This is partly due to the rigorous requirement of basing its use on site-specific, long-term (preferably 20 years) data for component parameters. Unfortunately, no alternative comprehensive models are available for the tropics, or indeed elsewhere. Elwell (1977, 1981) proposed a Soil Loss Estimation Model for Southern Africa (SLEMSA) which is a modification of the USLE for simplified application in developing countries. However, this model too requires some long-term data inputs and lacks the verification necessary for wider use. Below we will present available information for quantifying the individual causative factors for erosion in the tropics, whether or not they were intended for use in the USLE. By necessity, information from tropical regions will be contrasted with information from temperate areas, where most of the quantitative relationships originated.

Rainfall and Runoff Erosivity

Rainfall initiates the process of erosion by water whether it produces soil detachment and transport directly by raindrop splash or does so by overland flow. Therefore, it is of interest to examine some rainfall data from the tropics and subtropics (Table 27). For example, areas in the vicinity of Cairo, Egypt and Lima, Peru obviously are not generally subject to water erosion because of their negligible annual rainfalls (28 mm and 41 mm, respectively). Located as they are in the arid tropics or subtropics, these areas are more subject to wind erosion. However, many tropical areas receive more than 2500 mm (100 inches) rainfall per year, and many of them receive substantial rains every month (e.g. Manado, Celebes; Padang, Sumatra; Cairns, Queensland; Belém, Brazil). Others have dry periods of greater or lesser duration (e.g. Sittwe and Rangoon, Burma; Freetown, Sierra Leone; Cochin, India). Consequently, in these latter areas, rainfall is even more intense as it is concentrated within the more or less shorter wet season.

Perhaps nowhere are extremes in rainfall more evident than in Hawaii. In a 5-mile distance from Waikiki Beach to the head of the Manoa Valley on Oahu, annual rainfall ranges from < 250 mm to > 4050 mm. Mt. Waialeale on Kauai is considered the "wettest place on earth" with approximately 12,000 mm rainfall annually. Yet the business district of Honolulu receives about 650 mm yearly. Over 3150 mm of rain fell during March 1942 at Laupahoehoe, Hawaii[1] and 1972 mm was recorded

1. James Thrapp, Laupahoehoe Sugar Company, Hawaii. Personal communication, 27 April 1978.

Table 27. Rainfall in selected tropical and subtropical locations

	Number of months with > 76 mm	Mean annual rainfall (mm)
Africa		
Addis Ababa, Ethiopia	5	1260
Bathurst, Gambia	4	1295
Baloto, Congo	9	1539
Cairo, Egypt	0	28
Douala, Cameroon	10	4039
Freetown, Sierra Leone	8	4430
Mongalla, Sudan	7	998
Pretoria, South Africa	5	658
Yaounde, Cameroon	8	1560
Asia		
Bombay, India	4	2017
Cochin, India	8	2913
Colombo, Sri Lanka	11	2344
Hinatuan, Philippines	12	4305
Hong Kong	7	2162
Karachi, Pakistan	0	196
Kupang, Timor	5	1468
Madras, India	6	1270
Manado, Celebes	12	2657
Mandalay, Burma	5	828
Natrang, South Vietnam	4	1382
Padang, Sumatra	12	4486
Rangoon, Burma	5	2530
Saigon, South Vietnam	7	1984
Sittwe, Burma	7	5179
Australia		
Cairns, Queensland	12	4206
Darwin, Northern Territory	6	1570
Pacific Islands		
Apia, Western Samoa	12	2870
Arangka, Kiribati	7	1043
Atuona, Marquesas Islands	11	1215
Bora Bora, Society Islands	12	2031
Dillon's Bay, Vanuatu	10	1779
Enewetak, Marshall Islands	7	1470
Guam, Mariana Islands	12	2181
Hilo, Hawaii	12	3470
Honolulu, Hawaii	5	649
Matuku, Fiji	12	1777
Ponape, Caroline Islands	12	4875
Swain's Island, Amer. Samoa	12	2870
Caribbean and Central America		
Catacamus, Honduras	6	1255
Colon, Panama	10	3236
El Recreo, Nicaragua	11	3099
Guadalajara, Mexico	4	894
Havana, Cuba	7	1224
Merida, Mexico	6	925
Port-of-Spain, Trinidad	8	1610
San Jose, Costa Rica	7	1948
Vera Cruz, Mexico	6	1689
South America		
Asuncion, Paraguay	9	1316
Belem, Brazil	12	2770
Caracas, Venezuela	6	863
Georgetown, Guyana	11	2253
Inquisitos, Peru	12	2736
La Paz, Bolivia	0	555
Lima, Peru	0	41
Manaus, Brazil	9	2095
Quito, Ecuador	8	1115
Quixeramobin, Brazil	4	752
Rio de Janeiro, Brazil	8	1162

Sources: Blair and Fite 1965; Lamb 1972; Miller and Thompson 1975; Taylor 1973.

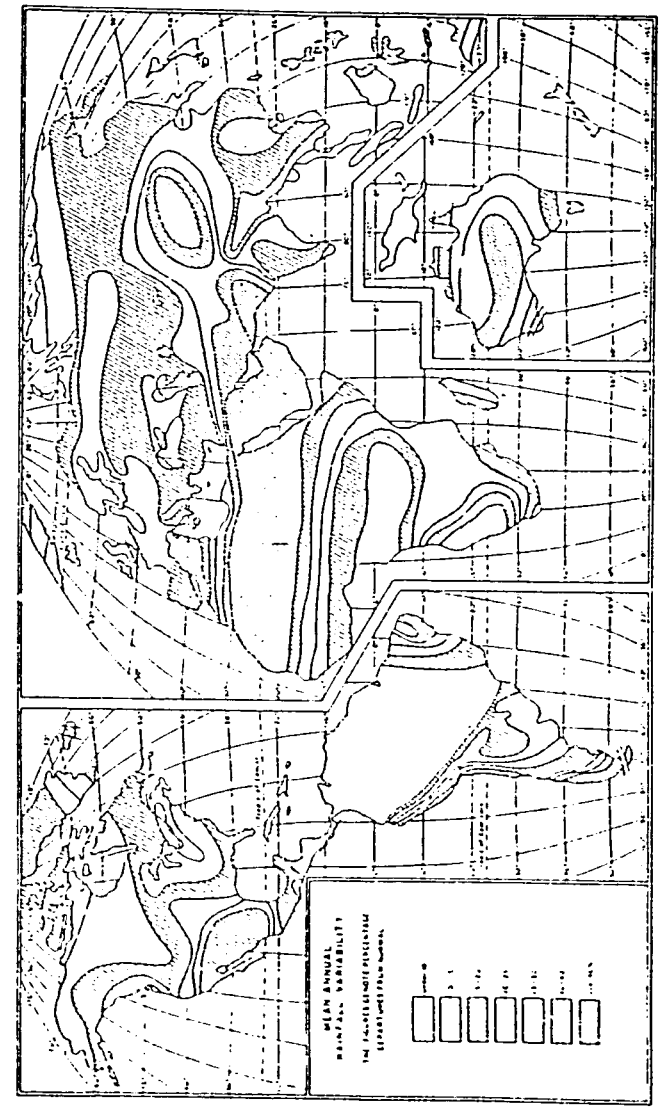
during 7 days in January 1979. Typhoon seasons in the western Pacific bring intense rains (Blair and Fite 1965). Luzon, in the Philippines, has experienced rainfalls of 1000–1250 mm within 24 hours. In Colombo, Sri Lanka, 250 mm of rain fell in 90 minutes (Burns 1947). However, the record 24-hour rain occurred on the island of Réunion at Cilaos in the Indian Ocean with a deluge of 1870 mm (73.6 in).

Although very useful for estimating relative erosion hazards, mean annual rainfall is not directly correlated with soil loss in the tropics. This apparent contradiction is partly due to the extreme variability in mean annual rainfall and seasonal rainfall patterns in given locations (Map 19); storm characteristics differ in different regions, as do other factors affecting the erosion process. For example, it may be recalled that the semiarid tropics are more prone to rainfall erosion than are the undisturbed humid tropics, as a result of the different qualities of vegetative cover (chap. 2, Fig. 7). Futhermore, the seasonal distribution of annual rainfall differs widely from one place to another (Maps 20–23). As expected, the concentration of rainfall in short seasons enhances its effectiveness for inducing erosion. Although the parameter of rainfall most related to erosivity of rain eluded researchers for many years, it has now been established that the characteristics of individual raindrops (number, size distribution, and terminal velocity) are of primary consideration in quantifying rainfall erosivity. Many studies have been made of raindrop size (Laws and Parsons 1943, Hudson 1963b) and terminal velocity (Laws 1941; Gunn and Kinzer 1949). Parameters directly related to these characteristics have been tested, with varying degrees of success. These included momentum (Rose 1960), kinetic energy (Mihara 1959) and intensity. Rose (1958) used simulated rainfall to study splash erosion of soils in Uganda. He found momentum per unit area of raindrop to be most closely correlated with soil loss. Hudson (1963) accumulated considerable data in Rhodesia showing that median raindrop diameter increased up to an intensity of 75 to 100 mm/hr but then decreased. Kowal and Kassam (1976) reported that rainfall intensities and median drop sizes are greater in northern Nigeria than in temperate or subtropical climates. Wischmeier and Smith (1958) found as a result of extensive statistical analysis that EI_{30}, the product of the total energy of a rainstorm (E) and the storm's maximum intensity for a 30-minute duration (I_{30}), gave the best correlation with soil loss. Soil losses from erosion stations were linearly correlated with EI_{30} as long as the other 5 factors of the USLE remained constant. To construct an erosivity map based on this index, it is clear that not only must long-term (20 yr) rainfall records be available but also such records must be available on a continuous-recording basis for individual storms. Calculations of storm energy from intensity data have been attempted by various authors (Table 28). The different units for expressing energy and intensity data are also shown in that table. Wischmeier and Smith's (1958) equation is now most widely used for calculating E; I_{30} is derived directly from continuously recorded storm data. Wischmeier and Smith (1978) provided a detailed procedure to accomplish such calculations in both English and metric units. Due to the unavailability of continuously recorded rainfall in many areas, these authors tested various alternatives for estimating the EI_{30} index (Wischmeier and Smith 1962). For the mainland United States, the 2-yr probabilities of 6-hr rainfall (P) were best for making these estimates. The relationship used was

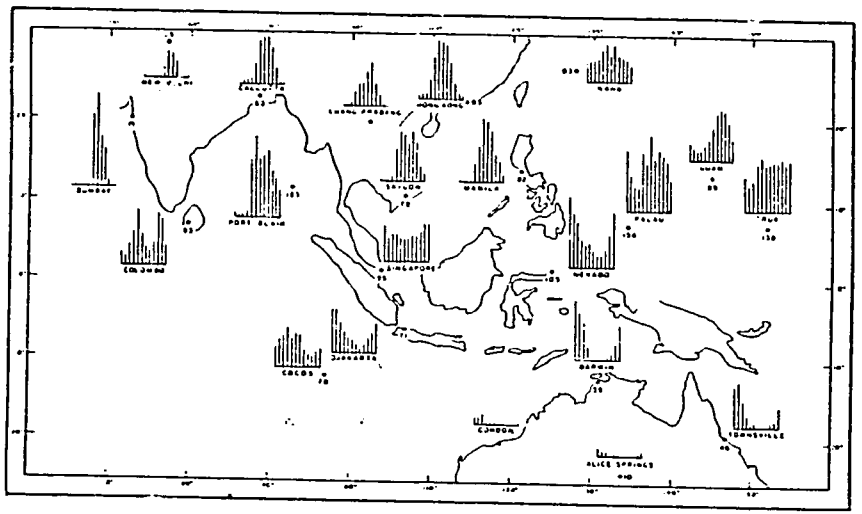
$$EI_{30} = 27.38P^{2.17} \qquad (2)$$

Based on this index, an isoerodent map was prepared for croplands of the United States east of the Rocky Mountains (Wischmeier and Smith 1965). Ateshian (1974) added erosivity values for areas west of the Rockies and proposed an analytical approach to estimate the rainfall erosion index. The original isoerodent map was later expanded to cover the western states and modified for the Southeast where the original higher values were found to overestimate soil loss (Wischmeier and Smith 1978). Rainfall index values on the recent map range from < 20 to 550 units. For Hawaii, the product of 5 yr-2 hr and 1 yr-6 hr rainfall was well correlated with EI_{30}. However, the correlative data base for the Hawaii study was so small (only 4 rainfall stations) that further tests of its validity are required. Estimated isoerodent maps for the islands are shown in Map 24. El-Swaify and Cooley (1980, 1981) reported erosivity index values ranging from 139 to 739 in selected locations on Oahu and Hawaii, showing clear voids in these maps.

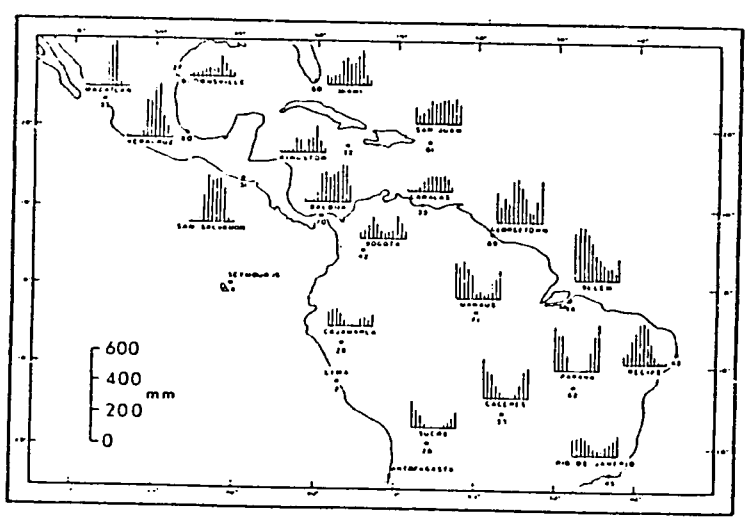
Several other attempts have been made to apply the EI_{30} index or indices closely correlated with it, for mapping rainfall erosivity in the tropics: Bols (1978) prepared a map following a regression analysis between daily rainfall and daily erosivity for 47



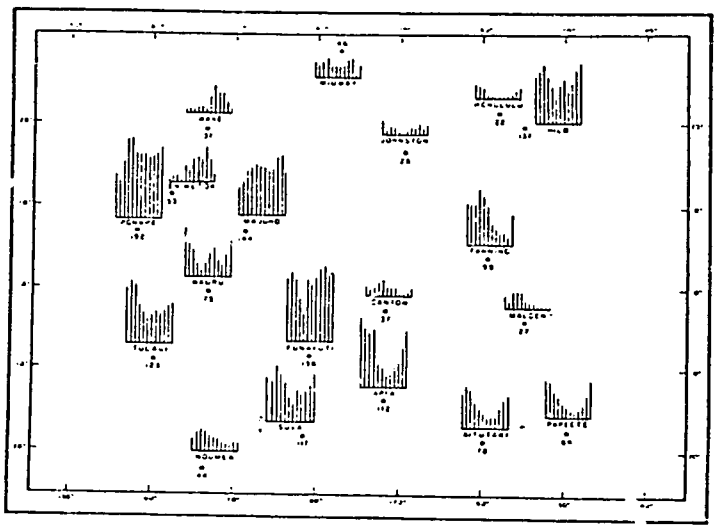
Map 19. Mean annual rainfall variability for the world. See text for explanation. (Atkinson 1971)



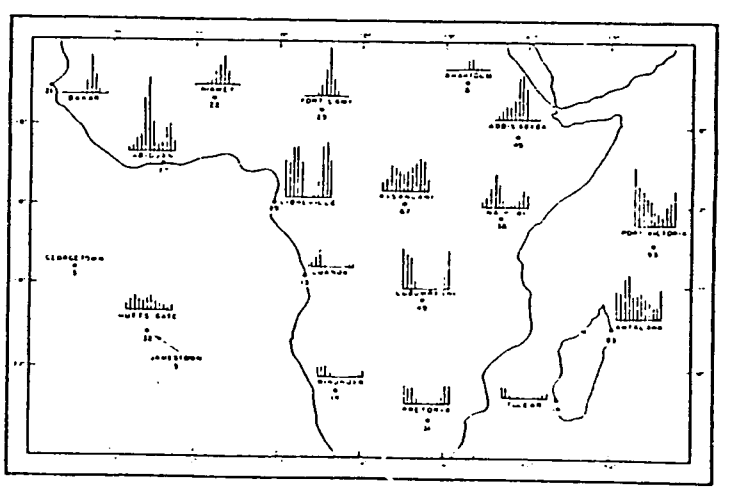
Map 20. Mean monthly rainfall for selected stations in Asia/Australia. Numbers next to place names indicate mean annual rainfall in inches. (Atkinson 1971)



Map 21. Mean monthly rainfall for selected stations in the Americas. Numbers indicate mean annual rainfall in inches. (Atkinson 1971)



Map 22. Mean monthly rainfall for selected stations in the Pacific and Africa. Numbers next to place names indicate mean annual rainfall in inches. (Atkinson 1971)

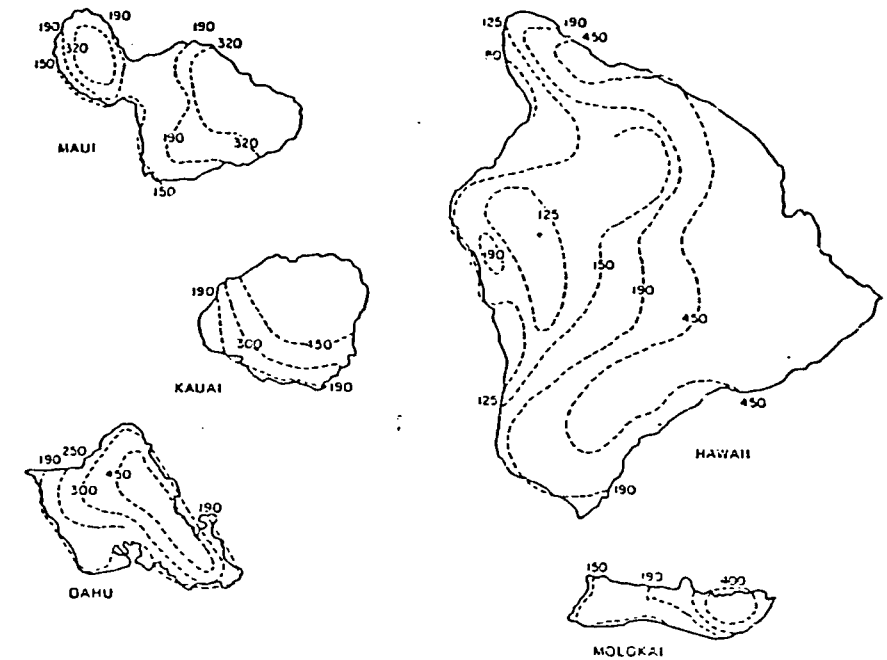


Map 23. Mean monthly rainfall for selected stations in Africa. Numbers indicate mean annual rainfall in inches. (Atkinson 1971)

Table 28. Interrelationships between raindrop size, storm kinetic energy, and intensity, as established by various workers

Location	Climate/Type of precipitation	Intensity range studied	D_{50} versus I	E versus I (Units of E)	E versus I (Units of I)	Reference
Washington DC	Temperate/ Predominantly frontal	0.03 to ≈2 in/hr Limited data 2-4.6 in/hr	$D_{50}=2.231^{0.182}$	--	$(\frac{in}{hr})$	Laws and Parson (1943)
		0.15-4.6 in/hr Extrapolated to 10 in/hr	--	$E = 916 + 331 \log_{10} I$ $(\frac{ft\ ton}{ac\ in})$	$(\frac{in}{hr})$	Wischmeier and Smith (1958)
Zimbabwe	Subtropical/ Convective thunderstorms	< 9 in/hr Limited data > 6.5 in/hr	Peak D_{50} of 2.55 mm at I of 3-4 in/hr	$E = 758.52 - \frac{127.31}{I}$ $(\frac{ergs \times 10^3}{cm^2})$	$(\frac{in}{hr})$	Hudson (1965)
Miami FL	Temperate/ Five types	≈0.1 to ≈9.5 in/hr Limited data > 6 in/hr	--	$E = 8.37\ I - 45.9$ $(\frac{ergs}{cm^2\ sec})$	$(\frac{mm}{hr})$	Kinnell (1973)
South Central USA	Temperate	< 10 in/hr Limited data > 5 in/hr	$D_{50}=1.63+1.331 - 0.33\ I^2+0.021^3$	$E = 429.2 + 534.0\ I - 122.51^2 + 78\ I^3$ $\frac{ft\ ton}{ac\ in}$	$\frac{in}{hr}$	Carter et al. (1974)
Western Nigeria	Humid tropical/ Convective thunderstorms	Approximately 0.5 - 9.5 in/hr	D_{50} Range: 1.5 to 4.5 mm D_{50} Increases with I	--	--	Aina et al. (1977)

Explanation of symbols: D_{50} is median volume drop diameter; E is kinetic energy per unit volume of rainfall; I is rainfall intensity. Units are reported as published by authors.



Map 24. Estimated average annual values of the rainfall erosion index in the major islands of Hawaii. (Wischmeier and Smith 1978)

rainfall stations in Java and Madura, Indonesia (Map 25); an erosivity map (Map 26) was prepared for the Indian subcontinent (CSWCRTI 1977); Bhatia and Singh (1976) indicated that EI_{30} was best correlated with soil loss for India; and Roose (1977*c*) used metric EI_{30} units to construct a rainfall erosivity map for West and Central Africa (Map 27).

The utility of the EI_{30} as a rainfall erosion index for the tropics has been critically analyzed by many workers. One important basis for criticism is the requirement of elaborate long-term rainfall records, which are not available in many developing countries. Another is the fact that successful use of the EI_{30} in certain temperate regions (such as its place of origin) does not guarantee its success as an index of soil loss in regions with substantially different climates, such as the tropics. The examples provided above, where the EI_{30} has been extended for use in different geographical locations have, by and large, not been justified by actual testing. As will be discussed in chapter 6, this is one of the high-priority research areas for understanding the rainfall erosion process in the tropics.

Approximating the EI_{30} index by well-correlated rainfall probability data may be equally criticized. In contrast to Wischmeier's procedure, many authors have sought a relationship between easily measured rainfall parameters and a rainfall erosivity parameter (Table 29). Good correlations between storm kinetic energy (E) and rainfall amount (A) were reported by Charreau (1969), while relationships between I_{30} and A were not well defined. A relationship defining EI_{30} as a function of A and of I_{30} (Delwaulle 1973) requires rarely accessible I_{30} data. Roose (1977*c*) showed that a relationship between EI_{30} and A alone was valid within a precision of 5 percent in the Niger, Upper Volta, Ivory Coast, Senegal, and Benin areas except where the ocean and mountains influence rainfall. This relationship was used to develop the EI_{30} map (Map 27). To bet-

ter describe the erosivity of tropical storms, Wilkinson (1975) modified the kinetic energy times maximum 30-minute intensity index (EI_{30}) for the soils and vegetative conditions of Nigeria. In calculating the erosion index, he did not begin the EI_{30} summation for a given storm until runoff occurred, therefore eliminating that portion of rainfall which was accepted by (infiltrated into) the soil. After testing several rainfall parameters in Nigeria against single storm soil loss from bare plots, Lal (1976*c*) found high correlations and insignificant differences between Hudson's KE > 1 (see next paragraph), EI_{30}, rainfall amount (A), maximum rainfall intensity for a minimum duration of 7.5 minutes (I_m), AI_m, and kinetic energy (E). Lal (1976*c*) also indicated that EI_{30} may underestimate the kinetic energy of tropical storms and suggested that the use of AI_m instead may be more advantageous. He was able to estimate this index linearly from rainfall amounts (A) at Ibadan, Nigeria, so eliminating the need for recording rain gauges. However, such simplification cannot be extended to other tropical regions unless a similar correlation can be successfully demonstrated. Furthermore, Lal emphasized the temporary nature of the proposed AI_m index because it is not based on kinetic energy considerations for tropical storms. Aina et al. (1977) discovered that AI_mV, where V is the terminal velocity of the median diameter raindrop, was best correlated with soil loss, whereas Kowal and Kassam (1976) established a relationship between E and A alone. Bailly et al. (1976) noted a good correlation between A and EI_{30}.

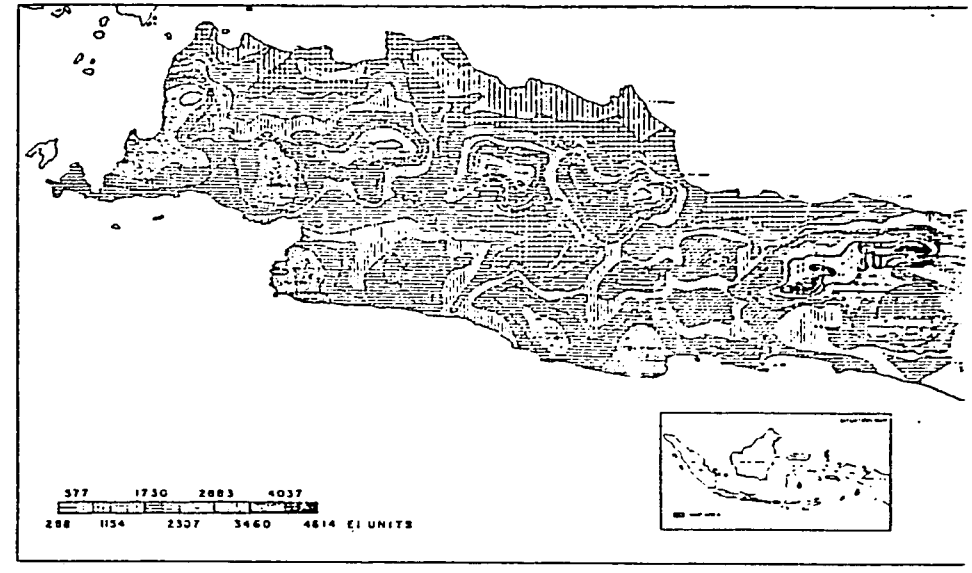
Other significant modifications of EI_{30} have been provided by various authors. Hudson (1971) defined the KE > 1 as the sum of the kinetic energies in storms resulting from intensities greater than 1 in/hr (25 mm/hr). He argued that such an index is more adequate for describing rainfall erosion hazards for tropical soils, which are generally characterized by well-structured profiles and infiltration rates greater than 1 in/hr. It must be noted that Wischmeier's EI_{30} index also omitted those storms of < 0.5 in (12.55 mm) which are separated by 6 hr or more even in the U.S. mainland (unless the maximum 15 min intensity was > 0.95 in/hr). Langbein and Schumm (1958) found that maximum sediment yield occurs in rivers when the annual effective precipitation is between 10 and 14 inches (254–356 mm). Annual rainfall less than 10 inches produced little runoff. The paradoxical decrease of sediment for higher rainfalls is attributed to the increase of vegetative cover. Arnoldus (1977*b*) stated that poor correlations between EI_{30} and soil loss were found in Benin, west Africa. Stocking and Elwell (1973*a*) found that EI_{15}, where I_{15} is the maximum 15 minute intensity, was best correlated with soil loss under limited cover in Zimbabwe. Elwell and Stocking (1973*a*) had found that the total cumulative momentum of the rain in all storms could be used interchangeably with energy without loss of accuracy in the EI relationship. Upon reexamining their data, they found the kinetic energy (KE) for storms with an intensity threshold of 4.3 mm/hr and above to be exponentially related to annual soil loss. Stocking and Elwell (1976) produced a map of mean annual erosivity for Rhodesia using this parameter (Map 28).

For other soils, crop types, and crop stages, Elwell and Stocking (1973*a*,*b*) found cumulative rainfall momentum above intensities of 2.1 mm/hr to be a better estimation parameter. A subsequent analysis of these data on a daily basis yielded correlations between soil loss and the product of rainfall energy and intensity (Stocking and Elwell 1973*a*). The intensity duration that provided the best correlations varied with the density of crop cover. They also combined soil loss data from grazing trials on a sandveld (Elwell and Stocking 1974) with the earlier data and determined that rainfall quantity parameters were useful for soil loss estimation (Elwell and Stocking 1975).

A distinctly different approach to estimating rainfall erosivity has been devised by Fournier (1960). He was also faced with a lack of recording raingauge data in his attempts to relate suspended sediment loads in African rivers (integrated in a specific degradation parameter in Tm/km²) to climatic parameters and topography (see later, this chapter, and Fig. 8). He successfully correlated annual specific degradation to a rainfall distribution coefficient C defined as $\frac{p^2}{P}$ where p is mean rainfall for the wettest month of the year and P the mean annual rainfall. His equation for the relationship between sediment yield (D) and the above coefficient is

$$D = K_1 \left(\frac{p^2}{P}\right) - K_2 \qquad (3)$$

with K_1 and K_2 being constants which he identified as important for the distinction between different climatic types (such as semiarid versus humid). Soil erosion is predicted by this equation only insofar as the suspended sediment load of a river is related to a



Map 25. Isoerodent map of Java and Madura. (Bols 1978)

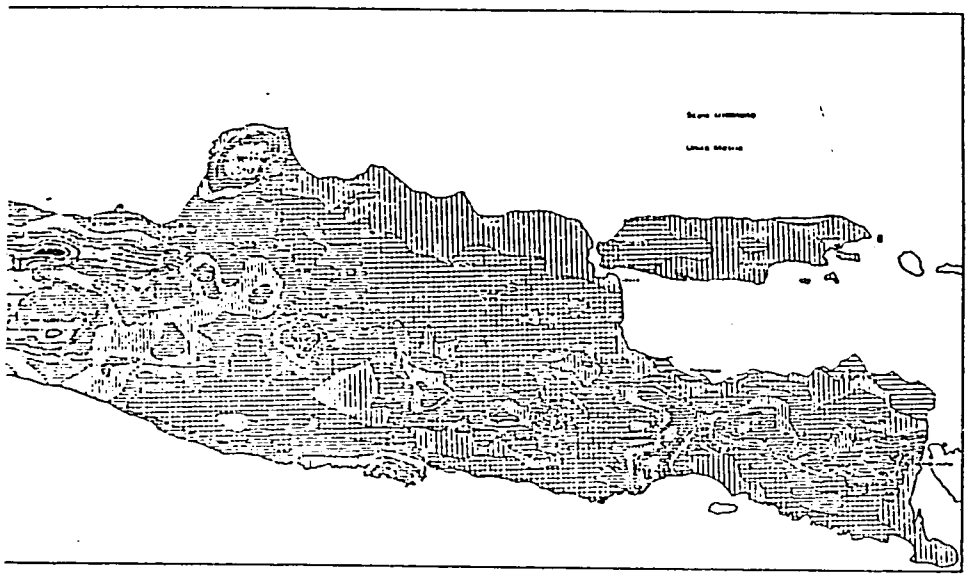
soil loss for the whole catchment. Since the rate of the soil loss is not uniform throughout most watersheds, more information and new techniques are needed to predict erosion on a surface area smaller than the whole catchment. In any case, the technique has been verified on watersheds with an area smaller than 2500 km². Arnoldus (1980) obtained poor correlations between the EI_{30} and Fournier's indices. He proposed as a modification of the Fournier approach, the quantity

$$\sum_{1}^{12} p_i^2/P$$

in which pi is monthly precipitation and P is annual precipitation. He obtained an improved correlation coefficient of 0.83 between this index and EI_{30} for 14 West African rain-gauge stations, and subsequently used this approximation of the R factor in the USLE to construct an isoerodent map for Africa.

Erosive rainfall in the tropics differs from that in other regions mainly in intensity and frequency characteristics. Rainstorms generally are more intense in the tropics, that is, the energy load of an individual storm is much greater than in temperate zones (Kowal and Kassam 1976). This is due to the larger size and greater number of drops falling per unit of time. Table 30 shows some of the observed maxima on record for erosive rainstorms. Table 31 shows comparative annual erosion index values for the tropics and nontropics. Both tables show the extreme aggressivity of tropical rainfall, which is generally explained by quantity, frequency, and intensity-drop-size characteristics.

Kowal and Kassam (1976) reported that about 60 percent of the drops in a typical storm at Samaru, Nigeria were > 3 mm in diameter. In Zimbabwe Hudson (1963) found that drops increase in size to an intensity of 63 mm/hr (2.5 in/hr) and then decrease. Blanchard (1950, 1953) reported that Hawaiian raindrops rarely exceeded 2 mm diameter (but these were for orographic rains) and also that drop sizes change with intensity in a pattern similar to Hudson's. Lal (1976*c*) indicated that because of high rainfall intensities over short durations as well as increased raindrop impact by wind enhancement, the erosivity index EI_{30} may underestimate the ki-

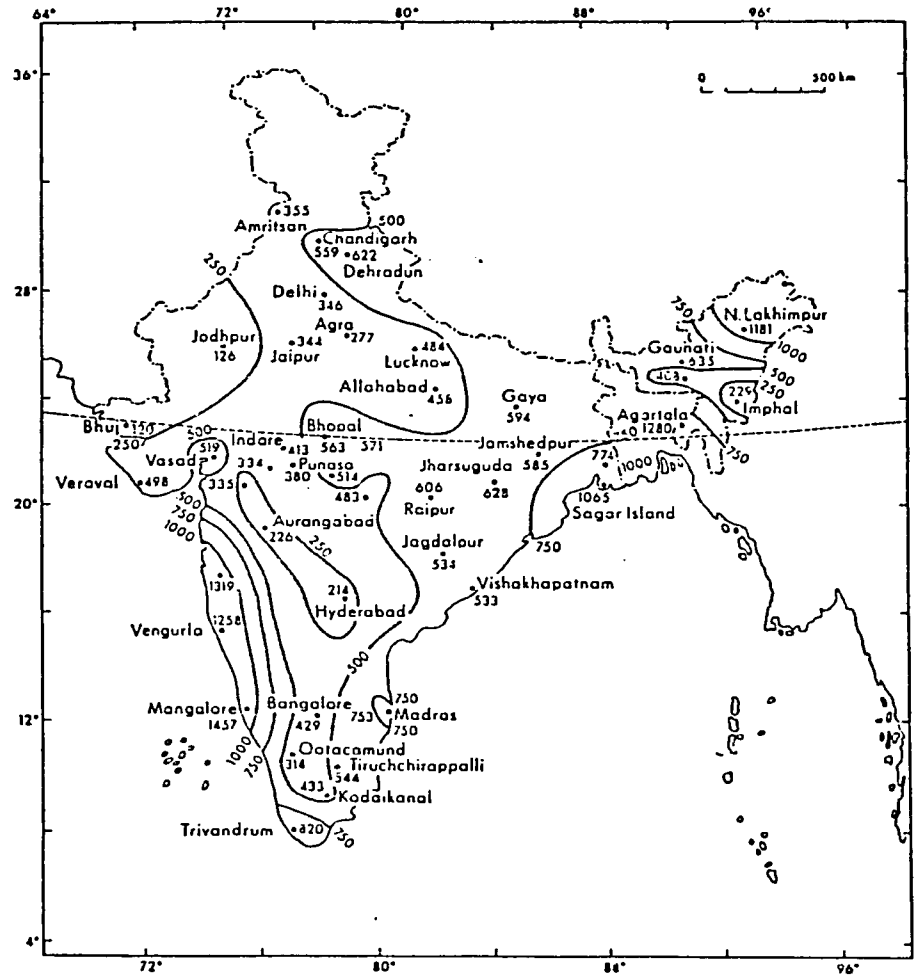


netic energy of tropical storms. However, in view of Hudson's peak drop size findings, older calculations may have overestimated storm energy, a problem which has been corrected by recent calculation methods (Wischmeier and Smith 1978). In many areas of the tropics thunderstorms occur with sharp, high intensity rainfall peaks, such as in western Nigeria (Wilkinson 1975). In the Hawaiian Islands thunderstorms are not as common. As for peak intensities, a short 4-second burst of 261 mm/hr has been recorded on the eastern coast of the island of Hawaii (Fullerton and Wilson 1974) with a specially designed rainfall intensity gauge. In northern Nigeria peak intensities of 120 to 160 mm/hr are not uncommon (Kowal and Kassam 1976); in Malaysia 200 mm/hr rainfalls are not unlikely.[2]

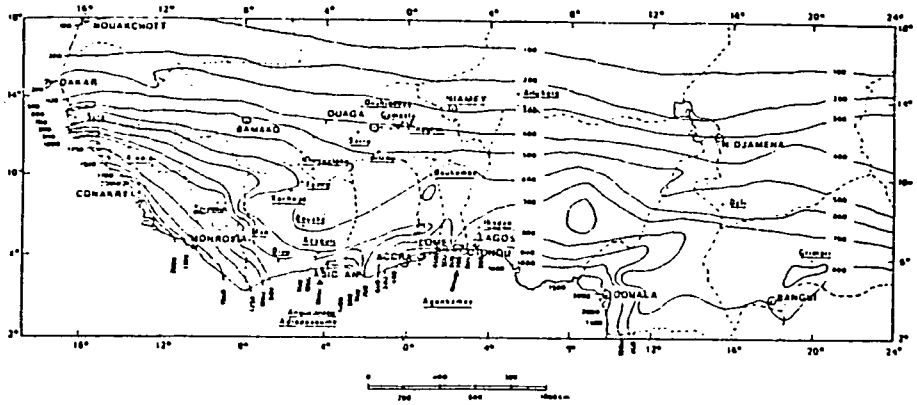
Erosive storms in the tropics may be infrequent in occurrence. Major soil losses in Colombia are due to only a few storms of high intensity (Suarez de Castro 1950). The same situation prevails generally in the Hawaiian Islands where a few so-called *kona* storms are the most hazardous. Similarly, at the experiment station in Mazoe, Zimbabwe (Hudson 1971) it has been found in almost all seasons that over half the total amount of erosion occurred in the one or two heaviest storms of the year. In one instance three quarters of the yearly loss took place in 10 minutes. Farther north in Upper Volta it was found that 88 percent of the annual erosion occurred in approximately 14 hours and 6 hours in 1956 and 1957 respectively (Fournier cited by Jackson 1978). However, Roose (1977*c*) states that in the dry or humid tropics the level of erosion is not determined by exceptional rain but by the sum of ten to twenty of the most erosive rainstorms annually.

More recently in the United States, an effort has been underway to separate the erosivity term into rainfall and runoff erosivity components. The extension of this idea to African conditions has not been attempted. Extreme climatic variability and the wide range of rainfall intensities and durations in the tropics seem to lend themselves well to such a versatile erosivity assessment technique. However, such distinctions are less necessary in the tropics than in temperate climates where water erosion

2. William Broughton, then of the University of Malaysia, Kuala Lumpur. Personal communication, 6 June 1978.



Map 26. Isoerodent map of India. (CSWCRTI 1977)

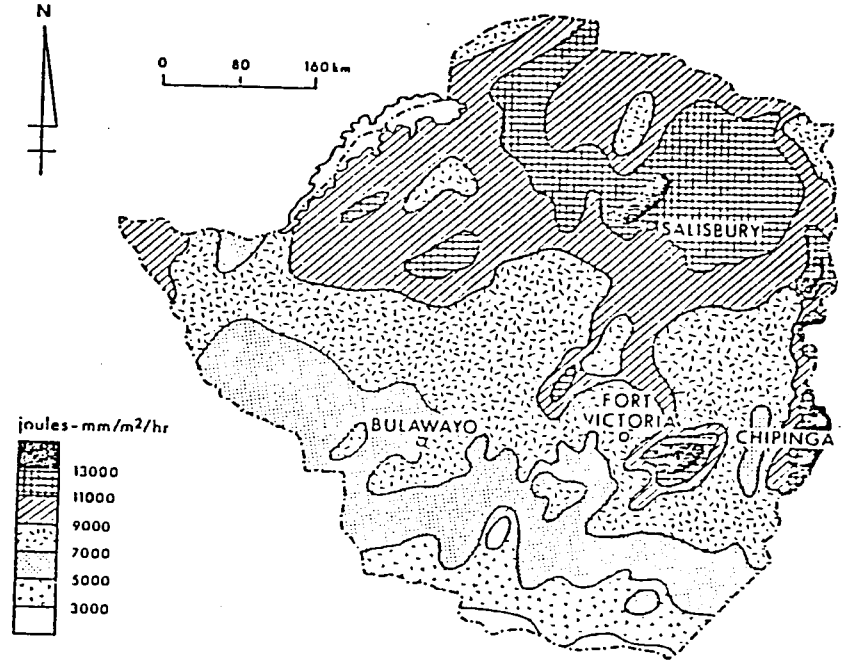


Map 27. Isoerodent map of west and central Africa. (Roose 1977c)

Table 29. Summary of alternative estimates for the rainfall erosion index and its components

Location	Climate (Average annual precipitation)	Relationship	Author's units: Qty	Author's units: Units	Reference
Sefa, Senegal	Tropical (1300 mm)	$EI_{30} = 1.2A - 4$ $E = 2.5A - 1$	A E EI_{30}	mm Kg m/m^2 ton/ha	Charreau (1969)
Allokoto, Niger	Dry tropics (495 mm)	$EI_{30} = 0.0158A\ I_{30} - 1.2$	A I_{30} EI_{30}	mm mm/hr ton/Km^2	Delwaulle (1973)
Western Nigeria	Tropical (1500 mm)	$E = (198+94 \log_{10} I_{30})A+24$	A I_{30} E	mm cm/hr ton m/ha	Wilkinson (1975)
Northern Nigeria	Tropical (1100 mm)	$E = (41.1A - 120.0) \times 10^3$	A E	mm ergs/cm^2	Kowal and Kassam (1976)
Large area of West Africa	Dry to humid tropical (500-2100 mm)	$\frac{R_{am}}{H_{am}} = 0.50$	R_{am} H_{am}	(ft ton/Ac)x10^4 mm	Roose (1977b)
Madagascar	Humid tropics (1300 mm)	$E = 2.325A - 3.945$	A E	mm ton m/Km^2	daily et al. (1976)

Explanation of symbols: A is rainfall amount; H_{am} is average annual rainfall amount; E is kinetic energy of rainfall per unit area of ground surface; EI_{30} is rainfall erosivity index after Wischmeier and Smith (1958); I_{30} is maximum intensity of rainfall sustained for 30 minutes; R_{am} is total yearly average EI_{30}.



Map 28. Mean annual erosivity over Zimbabwe (Rhodesia). (Elwell and Stocking 1976)

from runoff alone can be the major cause of soil loss—during the portion of the year when snowmelt prevails.

Soil Erodibility and Rillability Characteristics

The inherent susceptibility of a soil to erosion by water is collectively determined by its structural and hydrological properties. Thus aggregate breakdown and subsequent particle detachment from bare soil by a given rainfall (or overland flow) depends on aggregate stability and particle (or aggregate) size distribution characteristics. The likelihood of particle-transporting runoff occurring depends not only on rainfall characteristics but also on water transmission and rillability properties of the soil, particularly infiltration rates at the prevailing antecedent water contents. In the USLE (Wischmeier and Smith 1978) this susceptibility is quantitatively defined by the erodibility (K) factor, which has a potential maximum numerical value determined by the R value and the units of tons/acre/EI_{30} unit (Tm/ha/metric EI unit). As intended by the USLE, its experimental determination must be based on unit values for other factors in the equation. These are specified as follows: for R 100 EI_{30} units in ft-tons/acre/inch or 57.64 m-Tm/ha/cm; for L 72.6 ft or 22.1 m; for S a uniform slope of 9 percent; for C a bare, fallow, weed-free, frequently tilled condition for the two years preceding the initiation of measurement; and for P conventional row-crop tillage up and down the slope. Experimental determinations under natural rainfall must also represent a long term (preferably 20 yr, minimum 5 yr) mean value which encompasses a representative range of storm sizes, antecedent soil water contents, and other random natural variations.

Because of these rigorous requirements, with resulting time-consuming and expensive measurements, experimental values for the "real" erodibility of soils in general and tropical soils in particular

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Table 30. Selected data for high rainfall intensity rates in the tropics

Location	I(mm/hr)	Duration	Date
Plumb Point, Jamaica	792	15 min	5/12/62
Monrovia, Liberia	478	15 min	8/01/74
Miami, Florida	192	15 min	--
Colombo, Sri Lanka	170	90 min	1907
Ibadan, Nigeria	162	15 min	6/16/72
Waialua, Hawaii	142	15 min	4/18/74
Belvouve, La Reunion	121	9 hr	2/28-29/64
Belvouve, La Reunion	112	12 hr	2/28-29/64
Belvouve, La Reunion	91	13.5 hr	2/23-29/64
Cilaos, La Reunion	78	24 hr*	3/15-16/52
Cilaos, La Reunion	52	2 days	3/15-17/52
Baguio, Philippines	49	24 hr	7/14/11

Source: Modified from Jackson 1978, Lal 1977d, and unpublished sources.
*This storm produced the highest 24-hr rainfall on record (1869.9 mm or 73.6 in).

Table 31. Selected data for rainfall erosivity according to the EI_{30} index

Location	Index	Source
S. Louisiana	600	Wischmeier & Smith 1978
Mangalore, W. India	1457	CSWCRTI 1977
Conakry, Guinea	2000	Roose 1977c
Douala, Cameroon	2000	Roose 1977c
Laupahoehoe, HI	740	El-Swaify & Cooley 1980
Hilo, HI	780	El-Swaify (Unpublished)
Campinas, Sao Paulo	690	Lombardi Neto 1977
Jakarta, Indonesia	2307	Bols 1978

are rare. Therefore, rainfall simulators have been used by various workers to develop such values more quickly (Meyer and McCune 1958). However, because of the short-term nature of such measurements, certain precautions must be taken during both the data collection and analysis phases to ensure that simulated erodibility values correspond as closely as possible to "real" values (Dangler and El-Swaify 1976). The data reported below (Tables 32 to 37) include values obtained by both methods. For comparative purposes, and because certain soils are common between temperate and tropical regions, values for selected soils on the mainland United States are included.

From the tables it is clear that erodibility values for tropical soils vary so widely that to describe them categorically as resistant to erosion is misleading. Furthermore, it is evident from the wide spread of values within each order that soil orders, as a classification level, may be useful for descriptive relative assessments of erodibility class (e.g. Alfisols > Oxisols) but are insufficient as a quantitative tool for estimating K value. Of particular interest is the fact that soils in the same order but studied at different locations display wide discrepancies. For example in both Hawaii and Puerto Rico (Dangler and El-Swaify 1976; Barnett et al. 1971) it was found that Ultisols were very erosion resistant as indicated by their low K values. In contrast, in Central America and Venezuela (Popenoe 1976; Pla 1977) Ultisols covered a wide range from "extremely low" to "extremely high erodibility." In the mainland United States (Wischmeier and Smith 1978) this order also covered a wide range of resistance to erosion. More agreement is found universally for strongly aggregated Oxisols, the heavy clay Vertisols, and the weakly aggregated Alfisols; these orders possess low, moderate, and high erodibilities, respectively. It is important to note here that one possible source of the observed discrepancies is the use by different workers of many different soil classification systems. Therefore, a means of universal identification of soils is needed to insure uniform understanding of soil erodibility trends. The family level of classification in the U.S. Soil Taxonomy (SCS 1975b) is a likely tool for this purpose.

Table 32. Erodibility of soils classified as Alfisols or Aridisols

Series or Identification*	Type	Location	K Value	Source
Dunkirk	silty loam	Geneva, NY	0.69	Wischmeier & Smith 1978
Dayton		Oregon	0.54	Roth et al. 1974
St. Clair	subsoil	Michigan	0.48	Roth et al. 1974
Keene	silty loam	Zanesville, OH	0.48	Wischmeier & Smith 1978
McGary	subsoil	Indiana	0.36	Roth et al. 1974
Kawaihae	rocky silty loam	Hawaii	0.35	Dangler & El-Swaify 1976
Rabat		Morocco	0.35	Heusch 1970
Hagerstown	silty clay loam	Pennsylvania	0.31	Wischmeier & Smith 1978
Putat		Indonesia	0.26	Bols 1978
Gampala	Ferruginous	Upper Volta	0.25	Roose 1977b
Saria	Ferruginous	Upper Volta	0.25	Roose 1977b
Seta	Ferruginous	Senegal	0.25	Roose 1977b
Punang		Indonesia	0.14	Bols 1978

*Identification provided when series was not named.

Table 33. Erodibility of soils classified as Oxisols

Series or Identification*	Type	Location	K Value	Source
Molokai	silty clay loam	Hawaii	0.22	Dangler & El-Swaify 1976
Wahiawa	silty clay	Hawaii	0.14	Dangler & El-Swaify 1976
Bouoke	Ferralitic	Ivory Coast	0.12	Roose 1977b
Aptopodoume	Ferralitic	Ivory Coast	0.10	Roose 1977b
Agonkaney	Ferralitic	Benin	0.10	Roose 1977b
Korhogo	Ferralitic	Ivory Coast	0.02	Roose 1977b
Catalina-Cialitos	clay	Puerto Rico	0.01	Barnett et al. 1971

*Identification provided when series was not named.

Table 34. Erodibility of soils classified as Inceptisols

Series or Identification*	Type	Location	K Value	Source
Pakini	silty loam	Hawaii	0.55	Dangler & El-Swaify 1976
Naalehu	silty clay loam	Hawaii	0.21	Dangler & El-Swaify 1976
Waipahu	silty clay	Hawaii	0.19	Dangler & El-Swaify 1976
Kukaiau	silty clay loam	Hawaii	0.17	Dangler & El-Swaify 1976
Panduro	loam	Puerto Rico	0.11	Barnett et al. 1971
Hilo	silty clay loam	Hawaii	0.07	Dangler & El-Swaify 1976
Darmaga		Indonesia	0.04	Bols 1978
Juncos	clay	Puerto Rico	0.02	Barnett et al. 1971

*Identification provided when series was not named.

Table 35. Erodibility of soils classified as Mollisols or Vertisols

Series or Identification*	Type	Location	K Value	Source
Mayberry	subsoil	Nebraska	0.67	Roth et al. 1974
Pawnee	subsoil	Nebraska	0.45	Roth et al. 1974
Shelby	loam	Missouri	0.41	Wischmeier & Smith 1978
Marshall	silty loam	Iowa	0.33	Wischmeier & Smith 1978
Lualualei	clay	Hawaii	0.30	Dangler & El-Swaify 1976
Austin	clay	Texas	0.29	Wischmeier & Smith 1978
Jegu		Java	0.20	Bols 1978
Portageville		Missouri	0.05	Roth et al. 1974

*Identification provided when series was not named.

Table 36. Erodibility of soils classified as Ultisols

Series or Identification*	Type	Location	K Value	Source
Cecil	sandy clay loam	Georgia, USA	0.36	Wischmeier & Smith 1978
Tea	unnamed	Sri Lanka	0.31	Lal 1977d
Cecil	sandy loam	Georgia, USA	0.23	Wischmeier & Smith 1978
Waikane	sandy clay	Hawaii	0.09	Dangler & El-Swaify 1976
Freehold	loamy sandy	New Jersey	0.08	Wischmeier & Smith 1978
Humatas	clay	Puerto Rico	0.00	Barnett et al. 1971

*Identification provided when series was not named.

Table 37. Erodibility of soils with miscellaneous classifications

Series or Identification*	Classification	Location	K Value	Source
Marl	Clay mix	Morocco	0.6	Heusch 1970
Marl	Loose	Morocco	0.5	Heusch 1970
Marl	Cemented	Morocco	0.4	Heusch 1970
Marl	Sandy	Morocco	0.3	Heusch 1970
Schist	Acid	Morocco	0.2	Heusch 1970
Sentolo	Lithosol	Indonesia	0.14	Bols 1973
Citaman	Latosol	Indonesia	0.10	Bols 1978
Sands	Pebbly	Morocco	0.10	Heusch 1970
Limestone	Sandstone mix	Morocco	0.05	Heusch 1970
Darmaga	Latosol	Indonesia	0.03	Bols 1978

*Identification provided when series was not named.

The erodibility tables also show that surface and subsurface soil horizons possess different susceptibility to erosion. This is due to differences in the textural, mineralogical, and structural makeup of the various soil layers (Roth et al. 1974). Thus, different K values are needed for estimating soil losses from the same soil, depending on intended use. K values of surface soils are required for croplands while values for subsurface soils are needed for estimating soil loss hazards associated with construction activities.

A major criticism of available experimental K values for tropical soils stems from their being calculated according to the definition given earlier. Errors in calculation are likely if the base data for EI, L, and S factors are not applicable to the site under investigation. Indeed, it has been suggested by some authors that the low K values attributed to highly weathered tropical soils may not be strictly true, but rather a result of overestimated rainfall erosion indices as calculated by Wischmeier and Smith's EI_{30} value (1978). This criticism does not apply to data collected uniformly under controlled simulated rainfall such as those published by the present authors (Dangler and El-Swaify 1976) and also given in Tables 31-36.

The dependence of soil susceptibility to water erosion on textural, structural, and hydrological properties has been established by several investigators outside the tropics (Wischmeier and Mannering 1969; Wischmeier et al. 1971, Roth et al. 1974). These efforts culminated in the development of predictive approximations (e.g. for sand K = 0.05; for very fine sand K = 0.44; ARS 1975a), equations, and nomographs which were recommended by the respective authors for estimating K values whenever experimental values are not available (Figs. 21 and 22). These nomographs were put to wide use in the United States and in many other, including tropical, countries. Wilkinson (1975) and Roose (1977c) reported that soil erodibilities estimated from soil properties as described by Wischmeier et al. (1971) were satisfactory for some ferrallitic and ferruginous soils. Tables 38 and 39 show other examples of such use in South America and South Asia. Regardless of whether or not the absolute values are correct, relative trends again confirm the extreme variability in erosion susceptibilities (0.06-0.48) among tropical soils. El-Swaify (1977) and El-Swaify and Dangler (1977) criticized the use of mainland U.S.-based nomographs to predict the erodibility of tropical soils and provided preliminary data supporting the need for different predictive parameters to estimate tropical soil erodibility. These criticisms are founded first on the limited data base from which those nomographs were developed, thus either necessitating excessive extrapolation of nomograph values or rendering them completely inapplicable for use in tropical soils. Second, soil analysis procedures recommended for developing parameter values for use in the nomographs may not be appropriate to highly weathered soils.

The first criticism is clearly supported by the data in Table 40, which shows that prevailing textural classes, content of organic matter, and/or sesquiox-

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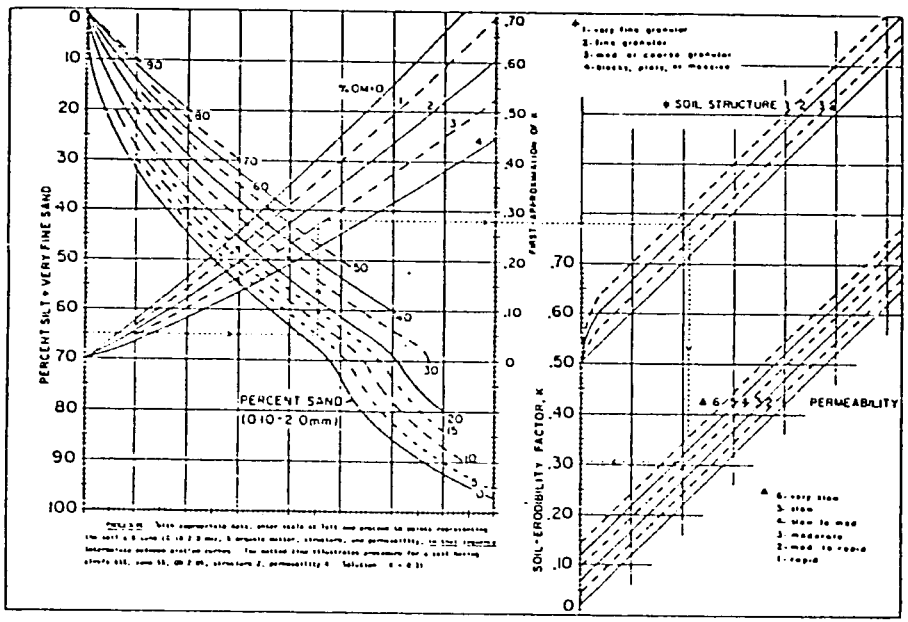

Figure 21. Wischmeier's nomograph for soil erodibility estimation. (Wischmeier et al. 1971)

ides of iron and aluminum generally fall outside the ranges covered by either nomograph. The second criticism is justified, particularly for oxidic soils, by the findings listed in Table 41. This table shows that the predicted erodibility value is clearly dependent on the methodology used to determine the particle size distribution in soil. It is well known that determination of tropical soil properties, particularly particle size and aggregate stability characteristics, is method-sensitive (El-Swaify and Lim 1977). Preliminary indications are that prediction of the erodibility of tropical soils requires parameters different from those that have been used successfully to predict the erodibility of temperate soils (El-Swaify and Dangler 1977; Table 42).

Although erodibility is presumed to be a constant, inherent characteristic of the soil (Wischmeier et al. 1971), this clearly is not the case. While certain soil characteristics that determine erodibility remain relatively unchanged (e.g. particle size distribution and mineralogical composition), others can undergo drastic change either naturally or because of management. These include organic matter content, tilth and aggregation properties, and the distribution of soluble and exchangeable ions (Singer et al. 1981). A major benefit of well-conceived predictive equations, therefore, is to make possible the periodic adjustment of a K value whenever appreciable changes in soil properties take place. Just as for initial determination of erodibility, repeated experimental determinations to detect these changes would be time consuming and probably prohibitive in cost.

Aside from the investigations summarized above, soil susceptibility to erosion has been reported by most authors only descriptively, or by numerical ranks at best. These are based partly on the quantitative findings discussed above and partly on general observations by soil scientists and conservationists, including the observation that poorly aggregated very fine sands and silts as well as easily dispersible silts and clays are highly erodible. In contrast, well-aggregated soils in which surface soil aggregates do not segregate from the underlying soil

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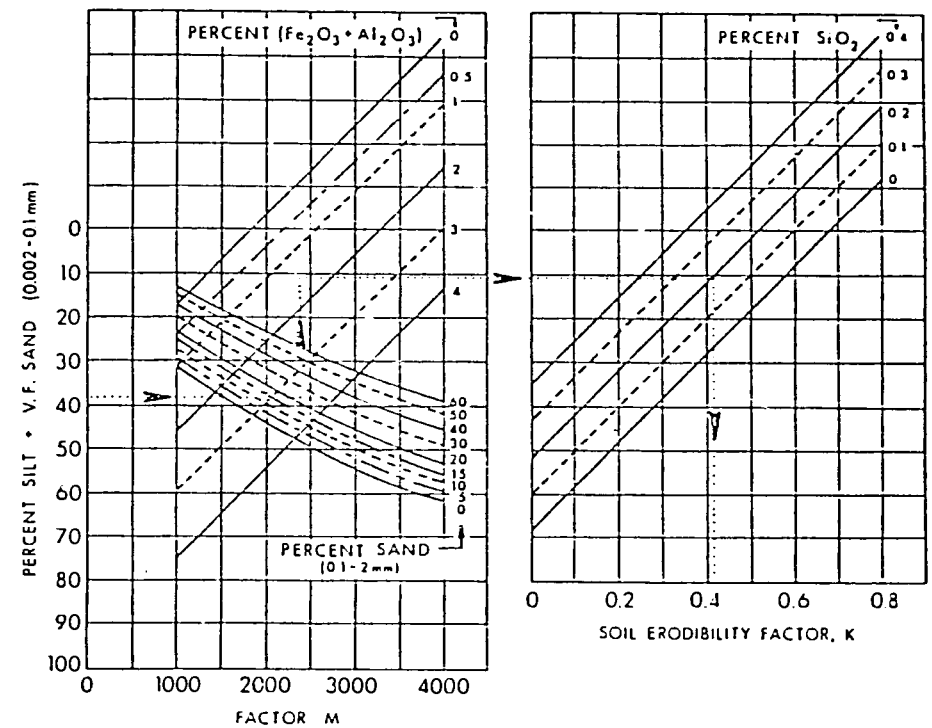


Figure 22. Roth, Nelson, and Romkens' (1974) nomograph for soil erodibility estimation.

mass (as do the irreversibly dried aggregates in Hawaii's Typic Hydrandepts) are less subject to detachment and rillability. Based on many observations, Middleton's (1930) dispersion ratio (the ratio between water-dispersed < 50μm particles and the total silt plus clay content of a soil sample) received wide use for ranking soil susceptibility to erosion. Bonnet and Lugo-Lopez (1950) evaluated "erosiveness" of Puerto Rican soils on the basis of Middleton's criteria. Later Lugo-Lopez (1969) attempted to simplify the laboratory measurement of erodibility by using the percentage of silt and clay in aggregates. Yamamoto and Anderson (1973) found that suspension percentage (the numerator in Middleton's dispersion ratio) was by itself the poorest of 13 erodibility indices in explaining splash losses from selected forest soils. In contrast, structural characteristics, as reflected by soil contents of aggregates in different size classes or by combinations between these and other characteristics, were well related to splash losses.

Rose (1960, 1961), studying splash erosion of some East African soils, discovered an indication that aggregate breakdown under artificial rainfall was a factor contributing to soil loss due to splash. He suggested that his detachment technique might, after further refinement, provide a sensitive and simple means of assessing natural differences in soil structure that influence detachment and erodibility. Pereira (1956a), also working with East African soils, looked for a simple test that would define the structural condition of a soil. He sought to combine in

Table 38. Nomograph-predicted erodibility values for some Brazil soils

Soil Identification	Range of K values, by horizon		
	A	B	C
*Podzolico Vermelho (Amarelo var. Lavas)	0.49-0.57	0.42-0.57	0.54-0.62
Serie Artemis	0.30-0.43	0.20-0.20	0.32
*Podzolico Vermelho (Amarelo--Orto)	0.16-0.38	0.16-0.40	0.43-0.59
Serie Godinhos	0.30-0.37	0.14-0.22	0.29
*Podzolico Vermelho (Amarelo var. Piracicaba)	0.28-0.36	0.11-0.17	0.15-0.22
Serie Quebra Dente	0.22-0.26	0.25-0.27	0.30
Serie Pau D'Alho	0.25	0.15	0.57
Serie Bairrinho	0.18-0.24	0.20-0.23	0.27
Serie Lagesinho	0.24	--	0.49
Serie Pompeia	0.20-0.22	0.18-0.25	0.42
Serie Tres Municipios	0.17	0.17	0.18
Serie Guamium	0.06-0.16	0.07-0.14	0.17-0.21
Serie Luiz De Quieroz	0.11-0.13	0.11-0.16	0.25
Serie Paredao Vermelho	0.10-0.12	0.11-0.12	0.10
Serie Monte Olimpo	0.09	--	0.15
Serie Tanquinho	0.06-0.07	0.06-0.09	--
Serie Iracema	0.06	0.07-0.09	--

Sources: *Freire and Pessotti 1974; others from Freire and Pessotti 1976.

Table 39. Nomograph-predicted erodibility values for some Sri Lanka soils

Soil Identification	Classification	K value
Katunayake	Sandy regosol	0.48
Batticaloa	Noncalcic brown	0.35
Kankesanturai	Red-yellow latosol	0.33
Mannar	Red-yellow latosol	0.33
Anuradhapura	Reddish-brown earth	0.27
Hambantota	Reddish-brown earth	0.27
Badulla	Red-yellow podzolic	0.22
Ratnapura	Red-yellow podzolic	0.22
Katugastota	Reddish-brown latosolic	0.17

Source: Joshua 1977.

Table 40. Comparison of range of properties used to develop existing nomographs with those encountered in selected Hawaii soils

Soil property and units	Range encountered		
	to develop Nomograph 1	to develop Nomograph 2	Selected Hawaii soils
Silt + very fine sand (0.002-0.1 mm) %	13.9-82.3	32.2-59.1	10.0-56.8
Sand (0.1 mm-2 mm) %	1.4-81.7	0.59-40.9	1.56-33.4
Clay (< 2μm) %	4.2-44.5	2.6-66.5	19.6-88.8
Organic matter, %	0.9-5.5	0.59-2.12	1.10-18.8
Soil structure class (1-4)	1-4	4	1-3
Soil permeability class (1-6)	1-6	6	1-5
Extractable Fe + Al (Sesquioxides) %	not given	0.97-3.76	3.62-34.3
Extractable Si, %	not given	0.12-0.32	0.0062×10^{-3} - 0.245×10^{-3}
Sources	Wischmeier et al. 1971	Roth et al. 1974	El-Swaify and Dangler 1977

Table 41. Comparison of nomograph-predicted and experimental erodibility values for Hawaii soils

Soil	Predicted K value based on			Experimental K
	Apparent texture	H_2O dispersion	NaOH dispersion	
Kawaihae	0.25	0.22	0.24	0.35
Hilo	0.07	0.03	0.03	0.07
Kukaiau	0.15	0.09	0.06	0.17
Naalehu	0.17	0.19	0.11	0.21
Pakini	0.09	0.09	0.05	0.55
Waipahu	0.14	0.10	0.10	0.19
Molokai	0.15	0.09	0.08	0.22
Wahiawa	0.07	0.19	0.05	0.14
Waikane	0.15	0.27	0.05	0.09
Lualualei	0.13	0.13	0.13	0.30

Table 42. Regression equations obtained at the 5th step of stepwise regression analysis for soil properties (excluding mineralogy) and erodibility of Hawaii soils under different antecedent moisture conditions

Equation No.		Equation
1	K_{dry}	$= 0.01250 + 0.01100\ LT250\mu + 0.00018\ \underline{MH} - 0.01722\ \underline{SUS} - 0.11106\ \underline{\Delta pH} - 0.03681\ \underline{pH}$
2	K_{wet}	$= 0.18946 + 0.00145\ \underline{BS} + 0.00036\ \underline{MH} + 0.00668\ \underline{BD} - 2.64034\ \underline{MWD} - 0.05927\ \underline{pH}$
3	$K_{weighted}$	$= 0.03970 + 0.00311\ LT250\mu + 0.00043\ \underline{MH} + 0.00185\ \underline{BS} - 0.00258\ \underline{SI} - 0.00823\ \underline{SA>100}$

Source: El-Swaify and Dangler 1977.

Legend:

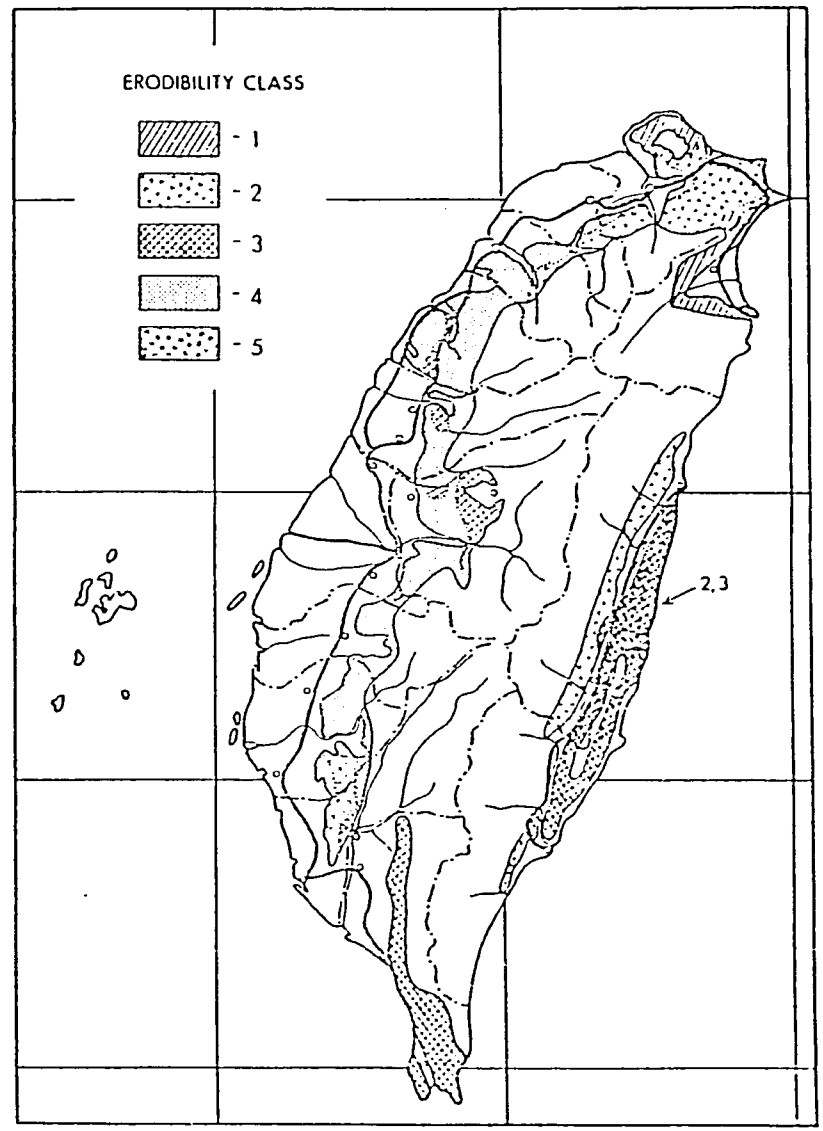
K_{dry}	Erodibility under dry antecedent moisture conditions.
K_{wet}	Erodibility under wet antecedent moisture conditions.
$K_{weighted}$	Mean weighted value for K_{dry} and K_{wet} as explained by Dangler and El-Swaify (1976).
$LT250\mu$	Unstable aggregates (%).
ΔpH	$pH_{KCl} - pH_{H_2O}$.
BS	Base saturation.
MWD	Mean weighted aggregate diameter, mm/25.4.
SI	Silt-sized particles (%).
MH	Sand >100μm(%) [silt-sized particles (%) + very fine sand (%)].
SA>100	Sand >100μm (%).
SUS	Suspension percentage (%).
BD	Bulk density.

one measurement of infiltration the effects of permeability of the soil and surface sealing resulting from aggregate breakdown under raindrop impact. Pereira was forced to conclude that while his test added to the information on infiltration, no single test was available to assess soil structural condition as it relates to erosion. The potential of this property as an index of erodibility is still unclear. Cormory and Masson (1964) noted that relative erodibilities of some Tunisian soils ranged from 1-12, and arranged their values to straddle K values of 0.1-0.5 in the quantitative system of the USLE. They tentatively assigned K values of 0.05 for Rendzinas with soft crust to 0.61 for calcareous brown soils on eroded marls. Fournier (1967) listed several factors likely to play a role in a comprehensive index of erodibility. These are particle size distribution, chemical composition as it affects flocculation and dispersion, organic and argillaceous colloids that may contribute to cementation of larger particles, cohesion and stability of soil aggregates, and the permeability of the subsoil. Fournier also presented data from Senegal to illustrate deterioration of structure and reduction of permeability with continued intense cultivation. He utilized Henin's "instability index" which is based on dispersed and aggregated particle size distribution and aggregate stability. As yet no relationship between these soil properties and erosion indices has been developed. Soils on sloping lands in Taiwan were classified in five categories of increasing relative erodibility and mapped accordingly by the Joint Commission on Rural Reconstruction (JCRR-MARDB 1977; Map 29). It is not clear how these categories may relate quantitatively to the K factor of the USLE.

An alternative system for estimating soil loss in Zimbabwe has been devised by Elwell (1977), based on a different quantitative definition of soil erodibility. This effort was made to reduce the need for expensive and time-consuming field plot studies for the determination of individual values of different erosion factors. In devising the "simplified" soil loss estimation model for southern Africa (SLEMSA), Elwell (1977, 1981) retained the "unit plot" concept of the USLE but included only three causative parameters of erosion:

$$Z = KCX \qquad (4)$$

where: Z = predicted mean annual soil loss, (Tm/ha/yr);
K = mean annual soil loss (Tm/ha/yr) from



Map 29. Relative erodibility of Taiwan slopeland soils. Classes 1-5 are in increasing order of erodibility. (JCRR-MARDB 1977)

Table 43. Soil erodibility values (F) used in the SLEMSA Model

Soil texture	Soil type	Basic index
Light	sands loamy sands sandy loams	4
Medium	sandy clay loam clay loam sandy clay	5
Heavy	clay heavy clay	6

Notes: Subtract the following from the basic index:

- 1 for light textured soils consisting mainly of sands or silts.
- 1 for restricted vertical permeability within 1 m of the surface, or for severe soil crusting.
- 1 for ridging up and down the slope.
- 1 for deterioration in soil structure due to excessive soil loss in the previous year (>20t/ha) or for poor management.
- 0.5 for slight to moderate surface crusting or for soil losses of 10-20 t/ha in the previous year.

Add the following:

- 2 for deep (>2m) well-drained, light-textured sands.
- 1 for tillage techniques which encourage maximum retention of water on the soil surface e.g. ridging on contour.
- 1 for tillage techniques which encourage high surface infiltration and maximum water storage in the profile e.g. ripping, wheel track planting.
- 1 for the first season of no tillage.
- 2 for subsequent seasons of no tillage.

Source: Elwell 1977.

a standard field plot 30 m x 10 m at a 4.5 percent slope for a soil of known erodibility under bare fallow;

C = the ratio of soil lost from a cropped plot to that lost from bare fallow; and

X = the ratio of soil lost from a plot of length L and slope S, to that lost from the standard plot.

In this case, the K factor incorporates both the kinetic energy of rainfall and soil erodibility and should not be confused with the K factor in the USLE. Rather, erodibility (F) is treated as a subcomponent of K and the authors defined a soil erodibility index by basic soil type. The core values for the index ranged from 4 to 6 but were adjusted depending on permeability, structure, and conservation practices (Table 43). Figure 23 provides an example of these relationships. The X factor in SLEMSA is the same as the LS factor of the USLE (see next section).

Landscape and Topography

It is evident in observing most forms of rainfall erosion, particularly massive gullies, ravines, and landslides, that, other conditions being equal, hilly and mountainous regions are especially subject to soil erosion. On the other hand, completely level areas are less subject to soil erosion than to drainage problems. Generally, however, the major cultivated lands of the world are between these extremes of steep slopes and level land. It has long been observed that higher erosional hazards are always associated with steeper slopes. Erosion workers and conservationists have also determined that, although effects on runoff are inconclusive, soil loss per unit area is higher for longer than for shorter slopes of equal steepness. Slope steepness in percent (s) and length in meters or feet (λ) are quantitatively incorporated in the USLE by the dimensionless factors S and L respectively. Remember that all parameters, when used within the USLE formulation,

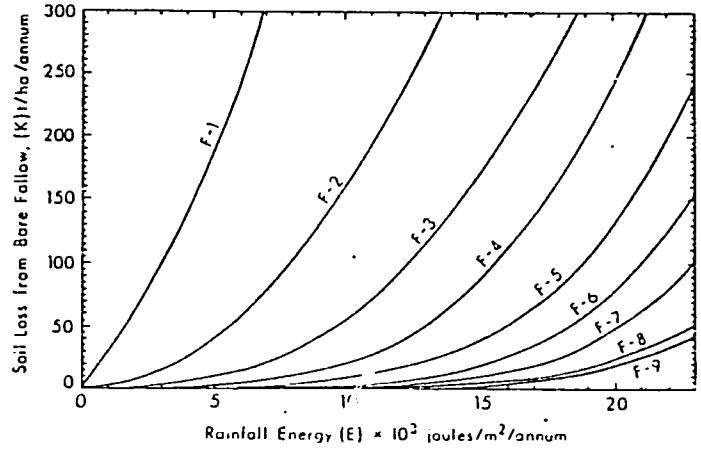


Figure 23. Relationships between K, E, and soil erodibility F. (Elwell 1977)

are intended for predicting losses from rill and interrill erosion only.

The exponential dependence of soil loss on slope steepness (or gradient) is generally accepted and has been verified by most workers (Zingg 1940; Musgrave 1947; Wischmeier and Smith 1965; Hudson 1971). In certain cases the dependence of soil loss on slope gradient was shown to take a pure power form:

$$E = cs^a \qquad (5)$$

in which E is soil loss, s is slope gradient, and c as well as the exponent a are empirical constants. The value of a varied from 0.4 to 2.0 depending on the experimental conditions used by the different workers. In other cases a quadratic form was obtained.

$$E = a + bs + cs^2 \qquad (6)$$

in which a, b, and c are empirical constants. Wischmeier and Smith (1965, 1978) using the latter form, calculated the dimensionless S factor for the USLE as

$$S = \frac{0.43 + 0.30s + 0.043s^2}{6.613} \qquad (7)$$

in which the figure 6.613 is the value of the numerator for a standard soil plot (s = 9%).

In the tropics several authors have confirmed the influence of steepness of slope on soil loss (Hudson and Jackson 1959; Fournier 1967; Roose 1975a; Lal 1976d). Here also, as expected, soil loss generally increased exponentially with slope gradient (Roose 1977c). However, among the few exceptions, Lal (1976b) and other workers reported that the presence of crop and mulch cover caused inconsistent relationships between soil loss and slope gradient. Roose (1977c) demonstrated the sensitivity of soil loss to even very small variations (0.25-0.5%) in slope steepness. Fournier (1967) earlier reported similar data with soil losses at Sefa, Senegal, increasing from 305-698 to 433-1420 T/m/km² when the slope of cropped land increased from 1.0 to 1.5 percent. The dependence of soil loss on slope was greater for sorghum than for groundnuts or rice. Figures 24 and 25 demonstrate the effects of slope on erosional losses from representative residual and volcanic ash soils, respectively, in Hawaii under wet antecedent conditions. It is interesting to note that soil erosion in both groups displays a linear dependence on slope gradient.

Slope length (λ) effects on soil loss are less well defined. However, general agreement exists among workers that, although runoff volume per unit area may be less for long slopes than for short, the greater total volume of runoff running down long slopes induces greater soil losses per unit area from the

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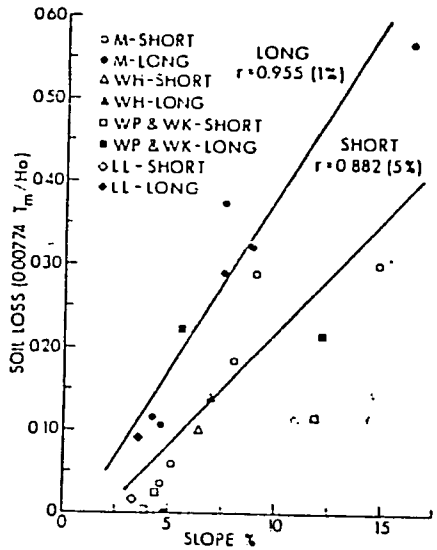

Figure 24. Relation between slope gradient and soil loss under 125 mm of simulated rainfall for residual soils on Oahu, Hawaii. Long and short refer to 24 and 11 m plots, respectively. Storms conducted at wet antecedent condition. (Dangler et al. 1976)

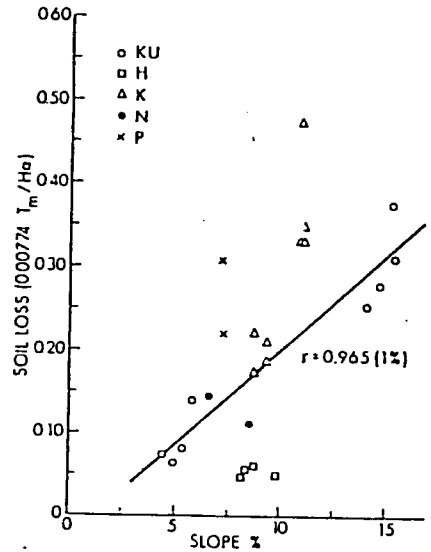

Figure 25. Relation between slope gradient and soil loss from 11 long plots under 125 mm of simulated rainfall for volcanic ash soi on the island of Hawaii. Storms conducted at wet antecedent con ditions. Ku = Kukaiau series; H = Hilo series; K = Kawaih series; N = Naalehu series; P = Pahoi series. (Dangler et al. 1976

longer than from the shorter slopes. It is further generally agreed that the dependence of soil loss (E) on slope length is in the form

$$E = b\lambda^m \qquad (8)$$

in which b and m are empirical constants. Values for the exponent m have been reported by several workers to range from 0.5 to 0.9, depending on the prevailing slope (Smith and Wischmeier 1957). The equation developed by those authors utilizes the exponent of 0.5 for slopes of 5 percent or steeper and has generally been accepted as satisfactory even in the tropics (Hudson 1971; Roose 1977*c*; Elwell 1977). For slopes of 3 percent or less the exponent becomes 0.3, and for 4 percent slopes it is 0.4 (Wischmeier and Smith 1958). Work in the tropics (Hudson 1957, Dangler et al. 1976) indicates that the exponent may have a different value from that used in temperate zones. Based on the data presented in Figure 24, m values within the range of data shown for residual Oahu soils, Hawaii, are calcula ed at 0.67, 0.76, and 1.1 for slopes of 4, 9, and 1 percent, respectively. This would indicate that th contribution of slope length (reflected in the effec tiveness of overland flow) to erosional losses fror these tropical soils exceeds that which may be est imated from the exponents used on the U.S. mair land (Wischmeier and Smith 1978). Based on hi equation, Wischmeier's L, a dimensionless facto for the USLE, has been calculated as

$$L = \left(\frac{\lambda}{22.13}\right)^m \qquad (9$$

where λ = slope length in meters, 22.13 m (72. ft) is the length for standard plots for which L = 1 and m is the exponent explained above.

In practice the values for the length and slope fac tors are generally determined as a combined topo graphic factor, LS from either tables or graph (Wischmeier and Smith 1965, 1978). Table 4

Table 44. Table for calculation of LS values as recommended by Wischmeier and Smith (1978)

Slope (percent)	Slope length in meters													
	7.62	15.24	22.9	30.5	45.7	61.0	91.4	122	152	183	244	305
0.5	.065	.080	.091	.099	.112	.122	.138	.150	.160	.169	.135	.197
1	.085	.105	.119	.129	.146	.159	.180	.196	.210	.222	.242	.258
2	.133	.163	.185	.201	.227	.248	.280	.305	.326	.344	.376	.402
3	.190	.233	.264	.287	.325	.354	.400	.437	.466	.492	.536	.573
4	.230	.303	.357	.400	.471	.528	.621	.697	.762	.820	.920	1.01
5	.268	.379	.464	.536	.656	.758	.928	1.07	1.20	1.31	1.52	1.69
6	.336	.476	.583	.673	.824	.952	1.17	1.35	1.50	1.65	1.90	2.13
8	.496	.701	.859	.992	1.21	1.40	1.72	1.98	2.22	2.43	2.81	3.14
10	.685	.968	1.19	1.37	1.68	1.94	2.37	2.74	3.06	3.36	3.87	4.33
12	.903	1.28	1.56	1.80	2.21	2.55	3.13	3.61	4.04	4.42	5.11	5.71
14	1.15	1.62	1.99	2.30	2.81	3.25	3.98	4.59	5.13	5.62	6.49	7.26
16	1.42	2.01	2.46	2.84	3.48	4.01	4.92	5.68	6.35	6.95	8.03	8.98
18	1.72	2.43	2.97	3.43	4.21	4.86	5.95	6.87	7.68	8.41	9.71	10.9
20	2.04	2.88	3.53	4.00	5.00	5.77	7.07	8.16	9.12	10.0	11.5	12.9
25	2.95	4.17	5.10	5.89	7.22	8.33	10.2	11.8	13.2	14.4	16.7	18.6
30	3.98	5.62	6.89	7.95	9.74	11.2	13.8	15.9	17.8	19.5	22.5	25.2
40	6.33	8.95	11.0	12.7	[illegible]	17.9	21.9	25.3	28.3	31.0	-	-
50	8.91	12.6	15.4	17.8	21.8	25.2	30.9	-	-	-	-	-
60	11.6	16.4	20.0	23.1	28.4	-	-	-	-	-	-	-

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shows the latest recommendations for calculation of the combined LS factor. It is based on the formula:

$$LS = \left(\frac{\lambda}{22.13}\right)^m \left(\frac{0.43 + 0.30s + 0.043s^2}{6.613}\right) \qquad (10)$$

in which all the terms have been explained above. Although Table 44 shows data for slopes ranging from 0.5 to 60 percent and lengths from 7.62 to 305 m, it is important to indicate that data for slopes less than 3 percent, greater than 18 percent, and longer than 122 m represent extrapolations beyond the range of research data that the authors had at their disposal. Therefore, the applicability of the data to the tropics must be particularly questioned where longer or steeper slopes are cultivated, as they often are under high population pressure in developing tropical countries. Even within the range of research data available, verification on tropical soils is lacking. The data in Table 44 are also intended for use on simple uniform slopes. To handle the real situation of irregular slopes, Foster and Wischmeier (1974) devised a refinement of the topographic factor as follows:

$$LS = \frac{\sum_{j=1}^{n} (S\lambda_j^{1.3} - S\lambda_{j-1}^{1.3})}{\lambda_e (72.6)^{0.5}} \qquad (11)$$

in which

- λ_j = distance from top of slope to lower end of any segment j in units of 3.28 meters (10 ft);
- λ_{j-1} = slope length above segment j in units of 3.28 meters;
- λ_e = overall length of slope in units of 3.28 meters;
- S_j = value of slope factor, S for segment j; and
- S = $(0.043s^2 + 0.30s + 0.43/6.613$ where s is the slope steepness in percent.

This equation may apply to irregular slopes by breaking them up into a series of segments each with uniform regular slope but having different gradients and probably different lengths.

An alternative topographic parameter, which was discussed earlier, is the "orographic coefficient" (OC), defined by Fournier (1962) as

$$OC = \frac{H^2}{S} \qquad (12)$$

in which H is the average height of surface relief catchment, in meters, and S the projected are the catchment in square kilometers (see chap. 2) considered the term $\frac{H^2}{S}$ to be an expression of r siveness of the landscape and found that OC w necessary modifying mathematical parameter ir analysis of correlation between specific degrada (based on river sediment loads for catchm > 2000 km²) and the climatic coefficient C (cussed earlier). He found a need for distinguisl between regions of "slightly accentuated rel (OC < 6) and those with "accentuated rel (CC > 6). Again, no evidence has been foun the literature of the applicability of Fourni topographic coefficients for predicting site-spe soil losses in the tropics.

As will be discussed in chapter 5, the relationsi between soil loss and runoff and topographic par eters provide the quantitative basis for selecting designing erosion control practices. Unfortunat most design criteria that have originated in United States are applied in tropical countries w little testing to seek improved alternatives.

Crop Cover and Residue Management

Long years of experience have shown that other f tors being constant, rainfall erosion from vegeta soils is determined by crop types, planting densi canopy characteristics, growth habits and quality stand, combination with other crops in space (int cropping) or time (rotation), contribution and m agement of ground-covering residue, and achieved growth stage development by the ti (erosive) rainfall arrives. Hudson (1957) conclusi ly demonstrated the role of crop or other low gro ing vegetative canopy as a rainfall interceptor t dissipates the kinetic energy of raindrops, th depleting the raindrop of its soil-detaching pow The presence of healthy vegetation also causes i creased infiltration, reduced runoff, increased moisture losses due to transpiration, binding of s by roots, increased soil organic matter (which c act as both a cover and an aggregate binder), a the slowing or obstruction of overland flow (Fi 13). Fournier (1967) provided an extensive accou of the recognized role of vegetative cover in soil er sion and conservation in Africa and Madagasca Hudson and Jackson (1959) noted an inverse rel tionship between productivity of maize and soil lo (Fig. 32). Krantz et al. (1978) demonstrated th fallow watersheds on Vertisols encountered far mo

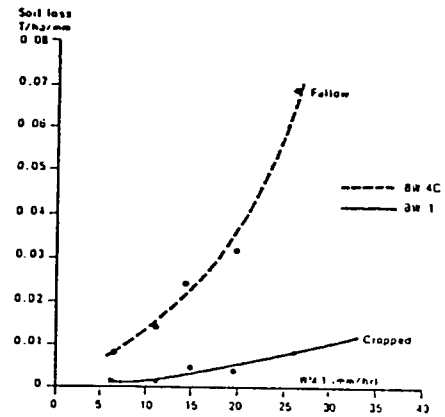

Figure 26. Comparative soil erosion from cropped and fallow Vertisols during the rainy season. (Krantz et al. 1978)

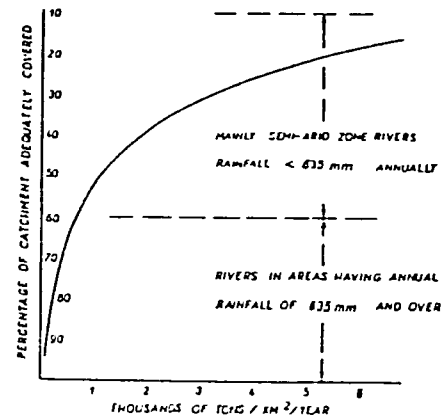

Figure 27. Relationship between catchment vegetation and soil erosion in selected rivers of Africa and Asia. (Balek 1977)

soil losses than cropped watersheds in the semiarid tropics (Fig. 26). Rimwanich[3] reported that soil loss from a fallow soil on a 7 percent slope in northeast Thailand amounted to 48 Tm/ha/yr compared with only 0.075 Tm/ha/yr under grass cover. Additional evidence for the importance of vegetative cover has been provided by Temple (1972) and Balek (1977) (see Tables 45, 46, Fig. 27). Dunne, Dietrich and Brunengo (1978) illustrated the effect of soil exposure by grazing on erosion rates in semiarid Kenya, and concluded that erosion rates accelerated dramatically as ground cover decreased between 20 and 30 percent.

Because of all the factors controlling crop cover effectiveness, a quantitative assessment of crop effects on soil erosion losses—the C factor—can become quite involved. For application in the USLE the C factor is defined as a dimensionless "ratio between soil loss from land cropped under specified conditions and corresponding loss from clean-tilled, continuous fallow" (Wischmeier and Smith 1978). Its magnitude may be derived experimentally from research plots designed to measure soil loss under the conditions required. Otherwise, to calculate its annual numerical value, cropstage periods must be defined and their duration as well as cover effectiveness (expressed as a soil loss ratio) estimated. Also needed are calendar dates coinciding with each of these periods and distribution curves for rainfall erosivity (EI values) during the year. Wischmeier and Smith (1978) provided the data required for such calculations in many states. Unfortunately, hardly any of the required experimental data or computational components listed above have been determined for the tropics. Sample data for Hawaii are shown in Table 47, and estimated loss ratios for selected tropical crops are provided in Table 48. The usefulness of these data will be limited to qualitative evaluation of crop cover effectiveness, as the dates associated with various agronomic practices and rainfall erosivity distributions within the year are required for cultivated locations in order to calculate the mean annual values of C. Such distributions are scarce for tropical regions.

Among other attempts to identify a C factor for cultivated crops in the tropics were those by Lal (1976*d*; Table 49) and Roose (1977*c*; Table 50). Both were developed in West Africa, the first on Alfisols and the second on both Alfisols and Oxisols. Elwell and Stocking (1971) analyzed soil loss data from grazing trials by Barnes and Franklin (1970) and developed a relationship between exposed soil and soil loss. A mean seasonal rating for exposed soil was evaluated by using an idealized exposed soil versus time model. Elwell and Stocking (1976) then considered the time distributions of crop cover and rainfall throughout the season, and developed a per-

3. S. Rimwanich, Land Development Department, Bangkok, Thailand. Personal communication, 1978.

Table 45. Runoff and soil erosion from various crops on identical plots at Mpwapwa, Tanzania

Year	Rainfall (mm)	Cultivated plot a	Cultivated plot b	Cultivated plot + narrow grass belts across slope a	Cultivated plot + narrow grass belts across slope b	Plot cultivated 50% grass a	Plot cultivated 50% grass b	Grass plot a	Grass plot b
1946/47	730	9.0	18.5	--	--	3.9	3.8	1.2	0.6
1947/48	520	16.4	11.3	--	--	10.4	2.1	3.4	0.3
1948/49	650	21.8	44.1	--	--	19.2	1.8	7.3	0.5
1949/50	560	12.8	8.3	--	--	13.1	0.6	4.7	0.2
1950/51	670	26.7	65.3	19.1	7.7	15.4	2.2	5.3	0.9
1951/52	850	28.9	86.4	10.0	30.3	9.0	1.8	6.5	0.7
1952/53	410	13.3	6.2	11.8	3.0	6.9	0.9	3.9	0.3
1953/54	520	25.5	48.8	21.2	37.2	14.3	3.4	7.2	0.4
Average	690	19.3	36.5	15.5	19.6	11.6	2.1	4.9	0.5
Average*		--	36.9	--	20.2	--	2.2	--	0.5

Source: Temple 1972a.
a = runoff as percentage of annual total; b = soil loss in m^3/ha (1.4 t/ha).
*Including soil washed to the bottom of the plot but prevented by the tank lip from entering the tank: for grass plot none.

Table 46. Runoff, soil erosion, and sediment concentration relationships at the Mpwapwa erosion plots, Tanzania

Season	Plot 1 Bare: uncult.	Plot 2 Bare: flat cult.	Plot 3 Bare: ridge cult.	Plot 4 Bulrush millet or sorghum	Plot 5 Grass	Plot 6 Bare: flat cult.	Plot 7 Decid. ungr.	Plot 8 Thicket
Percentage runoff of total precipitation*								
1933/34	52.9	34.8	25.2	29.1	2.8	33.3	?	?
1934/35	47.8	28.2	20.8	22.9	0.9	27.1	0.5	0.4
Average	50.4	31.5	23.0	26.0	1.9	30.2	0.5	0.4
Soil erosion in m^3/ha								
1933/34	97.0	80.4	20.9†	66.5	0	37.5	?	?
1934/35	98.7	90.0	44.7	37.5	0	25.0	0	0
Average	97.8	85.2	43.3*	52.0	0	31.3	0	0
Total sediment concentration in runoff in mg/l								
1933/34	42,295	51,180	53,280	37,515	-	25,745	-	-
1934/35	56,275	3,895	73,935	52,285	-	30,235	-	-
Average	49,240	63,993	63,608	44,900	-	27,990	-	-

Source: Temple 1972a.
*Rainfall 1933/34, 675 mm; 1934/35, 564 mm.
†Quantity relates to less than half the 1933/34 rainy season, before which ridges on contour and no soil loss. Average determined by doubling 1933/34 value and probably an underestimation.

Table 47. Sample data for estimated cropping-management (C) factors in sugarcane and pineapple fields on Maui, Hawaii

Crop and planting schedule	Average annual C value: Lahaina & Wailuku	Average annual C value: Pauwela
Sugarcane, irrigated		
Spring planted	0.13	0.18
Ratoon	0.11	0.14
Summer planted	0.15	0.17
Ratoon	0.11	0.14
Fall planted	0.27	0.27
Ratoon	0.21	0.21
Winter planted	0.23	0.24
Ratoon	0.18	0.18
Pineapple*		
Spring planted	0.17	0.19
Summer planted	0.29	0.18
Fall planted	0.31	0.31
Winter planted	0.20	0.24

Source: Brooks 1977.
*Factors listed include ratoon crop which consumes 12 months of the 18 month crop cycle.

cent cover-soil loss relationship. This approach was proposed as an alternative to the USLE cropping-management factor which requires extensive testing. The same authors attempted to separate crop management treatments that affect physical soil properties from those directly related to crop canopy characteristics. Their classification of different crop canopy types is shown in Table 51.

In addition to plant canopy, plant residues, as protective cover, are also a major component of C-factor calculations (Fig. 28). Alone, residues may also be an effective mulch against erosion (Table 52). In early studies in tropical Africa, Hudson (1957) noted the usefulness of mulch in erosion control, especially in the early part of the season before the crop has become established. Roose (1975b) found a few centimeters of straw mulch to be effective and later (1977c) classified mulching as an erosion control practice accounted for by a P (rather than C) factor (see Table 53). Lal (1976b) found similar results when he evaluated a range of mulch rates on different slopes. His reported relationship between mulch rate and a soil loss mulch factor was the same as that proposed earlier by Wischmeier (1973; Fig. 29). It is relevant to indicate here that residue management as a component of the overall crop-management scheme often represents a realistic means of soil erosion control that is perhaps the most amenable to the needs of the tropical small farmer.

Land Management and Support Practices

Even in ancient times, farmers discovered that shaping their lands in certain ways, such as contour planting and terracing (chap. 5), was necessary for sustained agricultural production. More recently, it has been realized that crop canopy and residue management and subsequent reduction of the C factors, are alone insufficient for controlling runoff and erosion on sloping lands. Thus, many forms of land shaping and preparation prior to planting have emerged in support of cropping factors. These will be discussed in more detail in chapter 5. For the present, it is important to indicate that the quantitative index for judging the effectiveness of such supporting practices is the P factor of the USLE. The conventional basis established by Wischmeier and Smith (1978) is tillage up and down the slope—presumed to induce the most soil loss among alternative practices—and is therefore assigned the maximum numerical P value of 1.0. Values based on U.S. data were assigned to the P factor by Wischmeier and Smith (1978) for contouring, contour strip-cropping, and contour terracing at slope steepnesses ranging up to 25 percent (Tables 54, 55, 56). No similar data are available for tropical regions. Perhaps more important, no such data have been determined anywhere for lands with slopes steeper than 25 percent, although these are often used by subsistence farmers in hilly tropical regions with rapidly increasing population density.

LAND-USE PATTERNS AND FARMING SYSTEMS

The parameters outlined in the previous section contribute physically to soil erosional losses associated with rainfall and runoff. However, manifestation of several of these factors is extremely dependent on the manner in which they are incorporated into existing land use patterns and farming systems. In particular, it is vital that any use of quantitative erosive parameters to design control measures (chap. 5) be done with full awareness of these patterns and systems to insure compatibility and some measure of success. The diversity of farming sys-

Table 48. Croopstage periods, durations, and estimated soil-loss ratios for selected tropical crops

Crop	Stage-description	Duration	Soil-loss ratio
Yams	1. Land preparation to planting	2 mo	.70-.60
	2. Planting to close in	4-5 mo	.60-.50
	3. Close in to full cover	2-3 mo	.50-.40
	4. Full cover to harvest	4-5 mo	.40-.20
	5. Harvest to land preparation	2-3 yr	.20-.10
Miscellaneous vegetables	1. Land preparation to planting	1 mo	.70-.60
	2. Planting to full growth	3 mo	.60-.40
	3. Full growth to harvest	1 mo	.40-.10
	4. Harvest to land preparation	1-3 mo	.20-.10
Pigeon peas	1. Land preparation to planting		
	a) Minimum tillage	2 wk	.40-.30
	b) Complete plowing	1 mo	.80-.70
	2. Planting to 2-3 months		
	a) Minimum tillage	1-2 mo	.30-.20
	b) Complete plowing	2-3 mo	.70-.60
	3. 2-3 months to harvest		
	a) Minimum tillage	1-2 mo	.20
	b) Complete plowing	2-3 mo	
	4. Harvest to land preparation	1-6 mo	.20
Coffee			
Sun grown	1. Land preparation to planting	1 mo	.40-.30
	2. Planting to 2 months	2 mo	.30-.10
	3. 2 months to first harvest	21 mo	.10-.05
	4. First to second harvest	12 mo	.05
Shade grown	1. Land preparation (hoeing, shade control)	1-2 mo	.30-.20
	2. Planting to 2 months	2 mo	.20-.10
	3. 2 months to first harvest	21 mo	.10-.05
	4. First to second harvest	12 mo	.05
Pastures			
Nonirrigated	1. Land preparation to planting		
	a) Minimum tillage	1 wk	.40-.30
	b) Plowing and sprigging	2 mo	.70-.60
	c) Furrowing and sprigging	1 wk	.50-.40
	2. Planting to close in		
	a) Minimum tillage	2 mo	.40-.20
	b) Plowing and sprigging	2 mo	.60-.20
	3. Close in to grazing or cutting	2 mo	.20-.05
	4. Grazing or cutting to full cover	1-2 mo	.05-.01
Pastures			
Irrigated	1. Land preparation to planting	2-4 wk	.80-.70
	2. Planting to close in	2-3 mo	.70-.20
	3. Close in to begin first grazing	2-3 mo	.20-.05
	4. Begin to end first grazing	2-4 wk	.05-.01

(Continued)

Table 48. (Continued)

Crop	Stage-description	Duration	Soil-loss ratio
Plantains	1. Brushing, plowing to planting	1 mo	.70-.60
	2. Planting to establishment	5-6 mo	.60-.30
	3. Establishment to first harvest	7-8 mo	.30-.20
	4. First harvest to finish harvest	2 mo	.20-.10
	5. Establishment to second harvest	7 mo	.10-.05
	6. Second harvest to finish harvest	2 mo	.05
	7. Finish harvest to rebrushing and plowing	2-3 yr	.05

Source: G. Martens, East-West Center, Honolulu, Hawaii. Personal communication, 1979.

Table 49. Soil loss coefficients for maize and cowpeas under different treatments on Alfisols

Slope (%)	Bare fallow	Maize-maize (conventional plowing, mulched)	Maize-maize (conventional plowing)	Maize-cowpeas (no tillage)	Cowpeas-maize (conventional plowing)
First season					
1	1.0	0.0	0.20	0.0	0.06
5	1.0	0.0	0.10	0.0	0.06
10	1.0	0.0	0.08	0.0	0.04
15	1.0	0.0	0.14	0.0	0.04
Second season					
1	1.0	0.0	0.11	0.0	0.19
5	1.0	0.0	0.04	0.0	0.08
10	1.0	0.0	0.04	0.0	0.06
15	1.0	0.01	0.16	0.03	0.39

Source: Lal 1976d.

tems and land uses in the tropics is great and would be difficult to discuss fully here. Instead, a brief outline of major patterns that emerge from a survey of the literature is presented.

Agricultural Cropping Systems

Numerous classifications of agricultural systems have been proposed for the tropics, for example, by Tempany and Grist (1958), and Ruthenberg (1971). One of the simplest (Ochse et al. 1961) refers to three general systems of agriculture, other than livestock farming, practiced in the tropics and subtropics: paddy (padi) or lowland rice; shifting cultivation; and intensive cultivation. Paddy culture is practiced in flat areas within the lowland tropics and requires excess water. Fields are farmed year after year under careful management in which fertility is restored by the addition of organic matter and the rain water that flows over the area. Erosion is generally limited in extent although losses of suspended fine clay may occur. Shifting cultivation is practiced on land incapable of being flooded for paddy. Initially, clearings are made in the jungle around a village. The farmer cuts trees into poles during the dry season and places them in piles, along with underbrush. Whereas the larger poles may be sold for fuel, the rest are burned. Crops are planted in small areas for one, two, or three years. The operation is conducted essentially at the family subsistence level. From the erosion standpoint, the most critical stage is during the onset of the rainy season when the soil surface is essentially bare during the first year immediately after planting. Another problem is the common invasion by *Imperata cylindrica*, cogon, and its subsequent takeover after forest clearing. This grass is so dense that it cannot be removed

Table 50. Estimated value of the C factor in West Africa

Practice	Annual average C factor
Bare soil	1
Forest or dense shrub, high mulch crops	0.001
Savannah, prairie in good condition	0.01
Over-grazed savannah or prairie	0.1
Crop cover of slow development or late planting (first year)	0.3-0.8
Crop cover of rapid development or early planting (first year)	0.01-0.1
Crop cover of slow development or late planting (second year)	0.01-0.1
Corn, sorghum, millet (as a function of yield)	0.4-0.9
Rice (intensive fertilization)	0.1-0.2
Cotton, tobacco (second cycle)	0.5-0.7
Peanuts (as a function of yield and date of planting)	0.4-0.8
First year cassava and yam (as a function of date of planting)	0.2-0.8
Palm tree, coffee, cocoa with crop cover	0.1-0.3
Pineapple on contour (as a function of slope)	
(burned residue)	0.2-0.5
(buried residue)	0.1-0.3
(surface residue)	0.01
Pineapple and tied-ridging (slope 7%)	0.1

Source: Roose 1977c.

by hand tools and may spread to form a savannah (Ochse et al. 1961). Intensive agriculture may be practiced on small holdings or on large plantations. Crops raised by monocropping include bananas, citrus, pineapple, coffee, cocoa, tea, rubber, spices, copra, palm oil, sugarcane, fibers, and others (Ochse et al. 1961).

A more extensive classification of agricultural systems in the tropics (Whittlesey 1936, cited by Tempany and Grist 1958) includes livestock. This seven-category system is presented briefly as follows:

a. Nomadic herding is found largely in arid regions.
b. Livestock ranching involves maintenance of pastures and improvement of the breeding stock.
c. Shifting cultivation is found most generally on the poorer upland soils of the tropics.
d. Rudimentary sedentary tillage is found on the more fertile soils of the uplands.
e. Intensive subsistence tillage exists predominantly in rice culture.
f. Intensive subsistence tillage without rice occurs on fertile soils with less rainfall than rice demands.
g. Commercial plantation crop tillage is generally restricted to monoculture of rubber, sugar, tea, coffee, bananas, and so on.

In the south of Brazil where few people live and land is abundant, land is farmed for one or two years and then left idle. Maize is planted up and down steep slopes, yet in the first year erosion is not reported to be a serious problem despite the heavy rain period. This may be due to the vigorous crop growth in the presence of initially adequate fertility and good soil structure. However, during the second year the fertility declines and soil structure changes so that runoff and erosion become significant. This phenomenon is also true of the tea estates in Brazil, which are planted on even gentler slopes than maize (Thomas 1967). This situation suggests that the initially good structure of the soils is so fragile that soil aggregates break down easily even after short periods of cultivation. Mixed farming involving both cattle and crops is apparently successful in a few tropical areas. The Teso district of Uganda and northern Nigeria are examples of such successes (Thomas 1967). However grazing alone or in mixed farming is associated with many serious erosion problems, particularly in semiarid regions.

The foremost erosion problem in Gwalior (Madhya Pradesh), India is from livestock. Since cows are sacred, they are not killed and during the dry season the problems of feeding become so severe that weeds and grass sod are cut from roadsides and wasteland to feed the animals (Pendleton 1940).

Table 51. Classification of crops based on similarities in soil protective characteristics

Description	Examples
A. Row crops	
1. tall, upright crops generally grown on unridged lands	annuals: maize, sorghum, sunflowers; perennials: napier fodder, sugarcane
2. leguminous, annuals; short, bunch, and procumbent varieties	beans: soya, velvet, jack, dolichos, and French; groundnuts; cowpeas
3. tall, upright crops grown on ridged lands	tobacco varieties, group 1 crops on ridges
4. woody, bushy row crops with individual growth and leaf development	cotton varieties
B. Broadcast crops	
1. tall, upright crops broadcast for fodder	see A1
2. short, leguminous crops broadcast for for fodder and green manure	see A2
3. medium height plants for fodder, green manure and weed fallow	sunn hemp, weed fallow
C. Orchards/plantations	
1. individual trees and bushes planted on a regular pattern	coffee, citrus, deciduous fruit
2. hedged crops	tea
3. thick stands of natural and exotic trees with little to no grass cover	forestry
D. Grasslands	
1. stoloniferous grasses planted in rows from runners; permanent pastures	star, Kikuyu, torpedo
2. seed established grasses usually broadcast; bunch varieties	love grass, Sabi panicum, Katamoora Rhodes, Giant Rhodes
3. species composition closely related to the natural regions soil types and condition of the veld	natural veld grasses, usually mixed species predominantly bunch grasses, both annual and perennial

Source: Elwell and Stocking 1976.

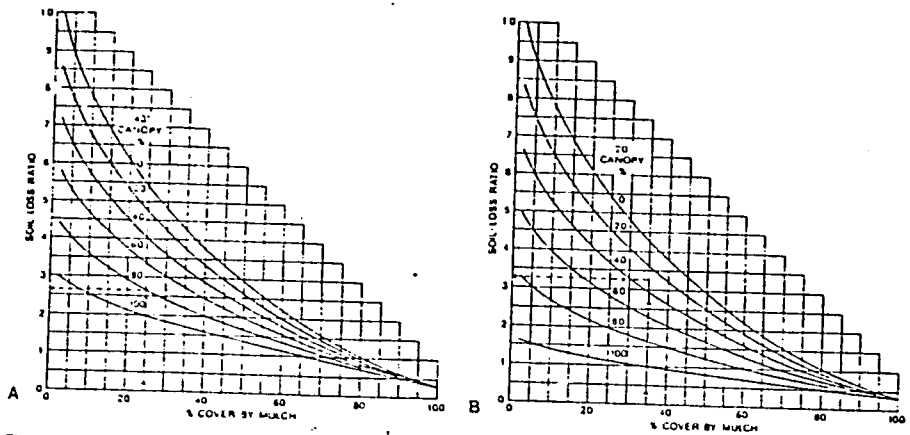

Figure 28. Combined mulch and canopy effects when average fall distance of drops from canopy to the ground is about (A) 1 m, (B) 0.5 m. (Wischmeier and Smith 1978)

Terraced farming has been tried in Africa, but generally has failed because the terraces have broken down. This system seems to work well only in densely populated areas such as those in Asia where sufficient labor is available to maintain and repair terraces. Similarly, Thomas (1967) observed that only in the densely populated areas of Africa and Asia will people make the effort to spread manure on crops.

Shifting cultivation is an important aspect of tropical agriculture and has a profound effect upon the land (Nye and Greenland 1960; Watters 1971). About 30 percent (36 million km²) of the world's exploitable soils, involving 200 to 250 million people, were reported as farmed in this manner (Hallick 1974; Lal 1974). It is known variously as slash and burn, *kaingin*, bush fallowing, milpa, *ladang*, patch, *agricultura nomada*, swidden, and other terms. A general definition of shifting cultivation is "any system under which food is produced for less than ten years from one area of land, after which that area is abandoned temporarily and another piece of land cultivated. The houses of the cultivators may or may not be abandoned when the land itself is abandoned; usually they are not." Abandoned land is recultivated after the fertility of the land is judged to be restored (Greenland 1974). In shifting cultivation a variety of crops are planted in the land area cleared by the cultivator. Sometimes as many as twenty species are planted at the same time, which generally means that the soil is fairly well protected from the erosive action of rainfall. The main difficulty with the system is that burgeoning populations have continually caused the fallow period to become shortened below the period necessary for restoring the soil to its former productivity level. Various ratios have been recommended for crop:fallow periods, such as 1:5 in Venezuela. In other sections of Latin America there is still much experimentation to find a proper ratio (Watters 1971). Whether shifting cultivation degrades the soil or not is a controversial question. Aside from the hazards associated with the areas cleared intentionally for cultivation, uncontrolled burning of forests has been cited as a cause of serious erosion (Lal 1974). Thomas (1967) provided an interesting description of African farms under shifting cultivation: To the European or North American, accustomed to neat and orderly fields of crops, such a farm presents a bizarre appearance in the forest. There is a great diversity of crops such as coffee, cocoa, banana, taro, and yams or if the soil is poor cassava and sweet potatoes. Helter-skelter as this system appears, it is a wise one as regards erosion-protection for each crop is gathered when ready. Thus enough cover is left to protect the soil from the drying effects of the sun and the erosive power of rain. Additional evidence exists to support shifting cultivation although many regard it as a primitive and inefficient system (FAO 1957). Interestingly, it appears that no general intensive method

Table 52. Soil loss ratios (percent) for final cropstage (harvest to plowing) when stalks are chopped and distributed without soil tillage

Mulch cover*	Corn or sorghum		Soybeans		
	Tilled seedbed†	No-till	Tilled seedbed†	No-till in corn residue‡	Grain stubble§
20	48	34	60	42	48
30	37	26	46	32	37
40	30	21	38	26	30
50	22	15	28	19	22
60	17	12	21	16	17
70	12	8	15	10	12
80	7	5	9	6	7
90	4	3	--	--	4
95	3	2	--	--	3

Source: Wischmeier and Smith 1978.
* Percentage of a field surface directly covered by pieces of residue mulch;
† This column applies for all systems other than no-till;
‡ Cover after bean harvest may include an appreciable number of stalks carried over from the prior corn crop;
§ For grain with meadow seeding, include meadow growth in percent cover and limit grain period 4 to 2 months. Thereafter, classify as established meadow.

Table 53. P factor for conservation practices in West Africa

Conservation practices	P factor
Tied-ridging	0.20-0.10
Antierosive buffer strips from 2 to 4 m width	0.30-0.10
Straw mulch	0.01
Curasol mulch (60 g/1/m²)	0.50-0.20
2-3 years of temporary grassland	0.5-0.1
Reinforced ridges of earth or low dry stone walls	0.1

Source: Roose, 1977c.

of mechanical agriculture has been found in the tropics to supplant the old style requiring only a digging stick and fire (Seavoy 1975). Belgian agronomists attempted to establish continual agricultural production in the Congo (now Zaire) to replace shifting cultivation. The system failed (Eckholm 1976).

Changes in soil productivity associated with land use after clearing have been evident but not well investigated. Soil structure deterioration begins as soon as the cycle of shifting agriculture begins. First, grass, bush, and forest trees are removed from the land to be cultivated. Mechanical removal and removal by burning of organic material from the soil surface sets the stage for soil structure deterioration and leaching of (originally recyclable) plant nutrients by rainwater. Nutrients supplied by decomposing plant remains lead to a brief fertility increase in the first year or two, after which a downward trend ensues due to leaching and removal of nutrients by crops. Allan (1965) illustrated such a trend. As the structure of the soil further deteriorates and weakened crops provide less vegetal cover each year, the danger of soil loss increases. The period of cultivation may range from one to a dozen or more years. When yields fall below the minimum level required for subsistence, the land is returned to fallow and is allowed to replenish its fertility under bush or forest vegetation. As the pressure on the food supply increases the level of subsistence return drops, that is, lower yields are acceptable and cultivation periods lengthen. An example from the Tiv area in Nigeria

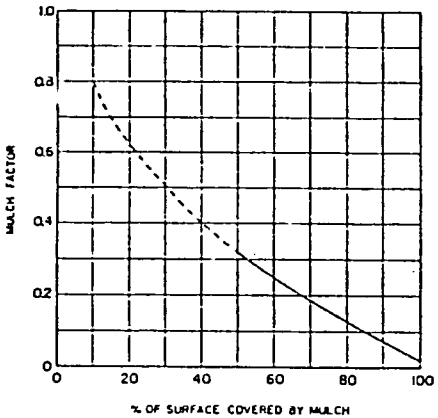

Figure 29. Effect of plant residue mulch on soil loss. Mulch factor is the ratio of encountered soil loss to corresponding loss without mulch. (Wischmeier 1973)

illustrates this problem. In this region, covering approximately 26,000 km² and supporting a population of 900,000 people, some of the more heavily populated areas (with more than 154.4 persons per km²) are showing a reduction in the fallow period (Vermeer 1970). Lands once fallowed for ten years now rest for only two. Declining yields have led to a longer "hungry season" at the end of the crop year and a movement away from yam production (yams require relatively more fertile soil for success) toward small grain production. Each year, more land goes out of production as fertility declines and erosion strips the soil and exposes underlying rock.

A major change in land use patterns in the tropics is that already, in places, the fallow periods of the shifting cultivation cycle have been abandoned altogether. This is happening at a time when the resource and technological inputs required to sustain agricultural production on cleared lands are ill defined. Continuous cultivation on moderately sloping land of an agricultural experiment station at Serere, Teso district, Uganda led to such intense erosion that in ten years the land had to be abandoned. Nearby soils of a similar erosion-resistant nature, suitable for permanent or semipermanent cultivation, showed only "a relatively small drop in soil productivity over twenty years" when two years of natural fallow followed three cropping years (Allan 1965). The acreage affected by reduced fallow periods and the impacts on productivity loss due to this reduction are not known even approximately. An American official with USAID has, as quoted from Eckholm (1976), "suggested that crop yields are declining 'in wide areas of Volta, the Guinea Coast, Zambia, Malawi, and Madagascar'." Eckholm continued with the observation that per capita food production in Africa has declined over the last twenty years.

The reason for yield declines under shifting cultivation are not entirely clear. An analysis of the properties of some Zambian soils led Ballantyne (1958), reported by Allan (1965), to conclude that loss of soil structure accounted for grain yield declines under shifting agriculture. Lal (1976c) has shown that soils commonly used in shifting agriculture suffer reduced infiltration, change in surface texture from finer to coarser, and reduced moisture-retention capacity with consecutive cropping. He hypothesized that soil erosion is the cause of these deteriorating characteristics. Reduced soil fertility is a generally accepted reason for yield declines and was illustrated by Ofori (1975). Hudson and Jackson (1959) have shown a direct relationship between soil loss and crop production (Fig. 19). See chapter 3 for additional information on erosion-productivity relationships.

Wild Lands

Forests, grazing areas, and other uncultivated lands, which often are in steep terrain, are termed "wild lands." When these are situated at the upper

Table 54. P values and slope-length limits for contouring

Land slope (%)	P value	Maximum length* (ft)
1 to 2	0.60	400
3 to 5	.50	300
6 to 8	.50	200
9 to 12	.60	120
13 to 16	.70	80
17 to 20	.80	60
21 to 25	.90	50

Source: Wischmeier and Smith 1978.
*These values may be increased by 25 percent if residue cover after planting will regularly exceed 50 percent.

Table 55. P values, maximum strip widths, and slope-length limits for contour strip-cropping

Land slope (%)	P values A*	P values B†	P values C‡	Strip width§ (ft)	Maximum length (ft)
1 to 2	0.30	0.45	0.60	130	800
3 to 5	.25	.38	.50	100	600
6 to 8	.25	.38	.50	100	400
9 to 12	.30	.45	.60	80	240
13 to 16	.35	.52	.70	80	160
17 to 20	.40	.60	.80	60	120
21 to 25	.45	.68	.90	50	100

Source: Wischmeier and Smith 1978.
* For 4-year rotation of row crop, small grain with meadow seeding, and 2 years of meadow. A second row crop can replace the small grain if meadow is established in it.
† For 4-year rotation of 2 years row crop, winter grain with meadow seeding, and 1-year meadow.
‡ For alternate strips of row crop and small grain.
§ Adjust strip-width limit, generally downward, to accommodate widths of farm equipment.

Table 56. P values for contour-farmed terraced fields*

Land slope (%)	Farm planning: Contour factor†	Farm planning: Strip-crop factor	Computing sediment yield‡: Graded channel sod outlets	Computing sediment yield‡: Steep backslope underground outlets
1 to 2	0.60	0.30	0.12	0.05
3 to 8	.50	.25	.10	.05
9 to 12	.60	.30	.12	.05
13 to 16	.70	.35	.14	.05
17 to 20	.80	.40	.16	.06
21 to 25	.90	.45	.18	.06

Source: Wischmeier and Smith 1978.
*Slope length is the horizontal terrace interval. The listed values are for contour farming. No additional contouring factor is used in the computation.
†These values may be used for control of interterrace erosion within specified soil-loss tolerances.
‡These values include entrapment efficiency of the catchment (see chap. 24) and are used for control of offsite sediment within limits and for estimating the field's contribution to watershed sediment yield.

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parts of river basins they will greatly affect water flow in the lower parts of the streams and rivers (Kunkle and Harcharik 1977). The highly beneficial effects of forests on controlling runoff are well documented (Bennett 1939; Kohnke and Bertrand 1959; Ahmad and Breckner 1974; Patric and Brink 1977). For example, in a comparative watershed study in Kenya, in which 76 mm of rain fell in 31 min at a maximum short-duration intensity of 254 mm/hr, it was found that a 32 ha housing development produced a flow of 2.15 m^3/sec through a flume installed in a grassed waterway. The peak rate through a similar installation in the adjacent forest watershed of similar area was only 0.056 m^3/sec, almost forty times lower (Pereira 1973). Infiltration rates are significantly higher in forests than in comparable agricultural or pastoral areas. In a Russian study, hardwood forests were found to have roughly six to twenty times higher infiltration rates than ploughed land (Molchanov 1963, cited by Kunkle and Harcharik 1977). In a tropical environment, a Hawaiian study of forestland versus adjacent agricultural land (pineapple, sugarcane) or pasture showed that 14 of 15 sites had much higher infiltration rates in the forest plots (1.2 to 500 times) than their counterparts under agriculture or pasture (Wood 1977). The same author reported that forested soils had greater porosities and less erodible aggregates than the non-forest-covered soils. In Nigeria, even in secondary forest (bush fallow), much higher infiltration capacities (horizontal plus vertical infiltration) were found when compared to such land after a year in crops. This was attributed, at least in part, to horizontal channels formed by the activity of ants and earthworms in the surface horizons of the forest soils, which disappeared after cultivation (Wilkinson and Aina 1976).

The valuable contribution of forest litter has also been realized by conservationists (Bennett 1939). Most importantly the twigs, mold leaves, stems, and bark fragments that comprise the litter act as a barrier to protect the pores and channels into which rainfall may infiltrate (Lowdermilk 1936, cited by Bennett 1939). In the presence of such protection, destructive effects of raindrop impact and formation of soil surface seals are unlikely. Secondarily, this ground cover serves as a sponge or blotter that absorbs and holds rainfall. However, this function is not considered as important as the safeguarding of soil pores against sealing and thus maintaining high infiltration rates and reducing runoff. Litter also contributes to slowing down the surface movement of runoff, thus allowing good water infiltration during longer contact with the soil. The surface of undisturbed forest soils is characterized by a thick, organic-matter layer with considerable biotic activity (Bates 1960). The organic matter fraction of soils has been correlated with aggregate stability (Baver 1968; Greenland 1971). Thus, a long-term benefit of rich forest litter is that it favors aggregate stability, a factor which earlier was shown to be strongly correlated with soil erodibility (El-Swaify and Dangler 1977).

At least half of the wood cut in the world each year is burned for fuel. Eckholm (1976) referred to this as "the other energy crisis." It is becoming increasingly difficult for people in India, Africa, Asia, and Latin America to obtain wood for fuel. For example, in Ougadougou, Upper Volta, 20 to 30 percent of a laborer's income is spent on firewood. A circle of 70 kilometer radius from Ougadougou has been denuded of trees by the the inhabitants of this city—and the circle is expanding (Eckholm 1976). The greatest scarcity of wood exists on the Indian subcontinent, where, as an alternative, many rural inhabitants use handmolded dung patties for fuel. This practice is rapidly spreading and subsequent loss of the major source of organic fertilizer is assured. Consequently the impoverished soils are further degraded (Eckholm 1976).

In the Philippines, at the peak of the dry season, vast areas of pasture are burned by ranchers in an attempt to eliminate the unpalatable (to cattle) old cogon *(Imperata cylindrica)* and to provide young growth for forage. When the rainy season commences, surface cover is scanty and erosion is thus enhanced. Furthermore, burning actually favors the establishment of *Imperata cylindrica* over other forage grasses. In the Ilocos region of the Philippines there is an unusual demand for fuel to cure tobacco. Tree cutting is intensive, so that in this mountainous region erosion is accelerated (Weidelt 1975).

Shifting cultivation is one of the main sources of deforestation in Thailand, resulting in increasing soil erosion (de Boer 1977). In Sabah, logging roads are established with a minimum of earthwork and slope gradients are disregarded; gradients of nearly 30 degrees are not uncommon. There is no attention to drainage by use of culverts or keeping the water on the inside of the road. Thus, erosion goes on during logging as well as for years afterwards. Ultimately, whole sections of roads slip and lead to formation of gullies (Burgess 1971). With the land rush on in Sabah there is growing concern that the forest will disappear as seems to be the fate of the lowland Dipterocarp forest in Peninsular Malaysia (Chim and Soon 1973).

Construction Activities

Poorly planned construction, whether for homes, factories, roads, or shopping centers, may cause serious erosion problems. The major difficulty results from the removal of the vegetative cover and topsoil, which impairs infiltration and favors runoff from rainstorms. For example, the construction of homes on what had been farmland in Kensington, MD resulted in 168 Tm/ha (75.6 tons/acre) soil loss per year (Guy 1965). A 2.65 km (1.65 mile) long logging road caused an increase of 250 times the sediment in runoff during the first storm following construction, in comparison to an adjacent watershed (Fredericksen 1965). In Tama New Town, which is a very large housing subdivision near Tokyo, (1200 mm annual rainfall) 15.4 mm/yr of soil were lost from loam and sand layers. After completion of pavements, drainage ditches, and the establishment of cover, the sediment yield approached zero (Kinoshita and Yamazaki 1975). A comparative study in the metropolitan area of Washington, DC in the United States showed that soil losses from construction sites varied from 100-500 Tm/ha/yr in contrast to soil losses of 3-7 Tm/ha/yr from nonconstruction areas (Chen 1974). Similarly, sediment loads in a stream from an area undergoing urbanization near Ottawa, Canada were 3 to 5 times as great as those from a neighboring rural area (Warnock and Lagoke 1974). Sediment yield was 91 Tm/ha during construction of an office complex over a two year period in Reston, VA. An adjacent forested area yielded negligible sediment. It was also found that installation of paved streets, parking lots, and buildings by no means reduced sedimentation proportionately. Increased runoff was considered to cause greater erosive power on the channel system (Guy 1974).

Ateshian (1974) found that an average of 31.3 percent of the total annual sediment from roadbanks was produced by the largest storm. However, for highway design work it has been pointed out that more reliable estimates of sediment yield may be made on a yearly or monthly basis than from individual storms (Diseker and Sheridan 1971).

An additional study of river sediments on the Coastal Plain and Piedmont areas of Maryland (Wolman and Schick 1967) indicated that sediment concentrations from construction areas ranged from 3000 to over 150,000 ppm; in agricultural catchments the highest concentration of suspended sediments was only 2000 ppm. In terms of annual loss this represents a maximum of approximately 500 Tm/ha/yr from construction sites. Road cuts in Georgia (Wolman and Schick 1967) produced comparable losses of roughly 180 to 490 Tm/ha/yr and surface losses of 3 to 6 cm from the road cuts in less than one year.

No quantitative information on the contribution of construction activities was available for developing tropical countries. However, the data presented above would indicate inevitable serious losses of soils during such activities whenever protective precautions are not followed. The extent and duration of disturbance associated with a specific construction activity will determine whether the magnitudes and impacts of resulting losses are as important as those affecting farms and wild lands.

El-Swaify, S.A., E.W. Dangler and C.L. Armstrong. 1979. Erosion control measures. In Soil erosion by water in the tropics: A state of the art. Washington, D.C.: United States Agency for International Development.

CHAPTER 5
EROSION CONTROL MEASURES

From the discussion of the causative factors of soil erosion in chapter 4, it is evident that several factors are subject to manipulation, a fact which provides the basis for erosion control. Among the parameters of the USLE, controllable parameters include primarily C (crop management), P (support practices), and LS (topography). While the soil susceptibility parameter (K) is generally presumed constant and inherent to the soil, it too can be changed by any means that alter soil structure. Such alteration is commonly achieved by tillage and amendment management practices such as in the reclamation of sodic soils.

Absolute prevention of soil erosion is unattainable and often unnecessary; therefore a realistic goal is to keep soil losses within "tolerable" limits as defined in chapter 1. If this can be achieved throughout the tropics, a major step will have been taken toward alleviating critical world food shortages and reducing the frequently calamitous effects of erosion discussed in chapter 3.

Conservation has come to mean the wise use of resources. Given that, according to a widely used estimate, a foot of soil generally requires more than a thousand years to form, limiting soil losses is mandatory if future human generations are to survive. We must learn to blend our land use more harmoniously with the environment, as the recent concern with ecology has taught us. We are rapidly running out of new locations of arable land. With the human population expected to double by the early part of the twenty-first century, we must conserve (wisely use) existing soil resources and limit the exponential population growth. While the latter problem must be solved by other disciplines, dwindling soil resources and soil productivity are our problem. Herd sizes exceed the carrying capacity of the land in many developing nations; vast tracts of timber are clear-cut and logging roads are built without regard to ecological consequences, especially in Southeast Asia; shortened fallow periods in shifting cultivation render that practice little more than intensive agriculture without the inputs required for sustained productivity; emigration is followed by resettlement on fragile soil systems which require careful management to support agricultural crops, as appears to be evident in Amazonia and Indonesia; throughout the tropics wholesale destruction of woody plants to obtain firewood leads to removal of cover. The list goes on. All result in ever-increasing soil losses.

The first step in a conservation plan should be an inventory and classification of lands for their best possible use. Such a plan should recognize the limitations and constraints that may have to be considered to use a particular land area wisely. The land capability concept was first developed in the United States (USCS 1948; Klingebiel and Montgomery 1961), but physical and socioeconomic conditions are so different in the tropics that the U.S. classification is not relevant—either to most lesser developed countries (LDCs), or to excessively steep slopes anywhere. Erosion risk assessment should be recognized as an integral part of land classification (Blair-Rains 1981, Douglas 1981, Bennema and De Meester 1981). "Sheng's scheme of land capability classification for Jamaica" (Sheng and Stennett 1975) serves as a model for developing countries, especially those with predominantly hilly land (see Table 57). Preparation of such a classification is a first step. If land use is planned so as to conform either to this classification or a similar one, many erosion problems could be avoided at the outset and later minimized. In the words of the proverb, "An ounce of prevention is worth a pound of cure." The basic principles of erosion control involve the dissipation of raindrop impact which limits soil detachment and favors water infiltration, and reduction of runoff volume and velocity which diminish sediment transport. Much of this can be achieved on cultivated lands by enhancing the concepts of good

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Table 57. Sheng's scheme of land capability classification for Jamaica --a treatment-oriented scheme especially for hilly watersheds

Slope / Soil depth	1. Gently Sloping <7°	2. Moderately sloping 7° - 15°	3. Strongly sloping 15° - 20°	4. Very strongly sloping 20° - 25°	5. Steep 25° - 30°	6. Very Steep >30°
Deep (D) > 90 cm	C_1	C_2	C_3	C_4	FT	F
Moderately deep (MD) 50-90 cm	C_1	C_2	C_3	C_4 / P	FT / F	F
Shallow (S) 20-50 cm	C_1	C_2 / P	C_3 / P	P	F	F
Very shallow (VS) <20 cm	C_1 / P	P	P	P	F	F

Source: Sheng and Stennett 1975.

1. Symbols for most intensive tillage or uses:

C_1 Cultivable land 1, up to 7° slope, requiring no, or few, intensive conservation measures, e.g. contour cultivation, strip cropping, vegetative barrier, rock barrier, and in larger farms, broadbase terraces.

C_2 Cultivable land 2, on slopes between 7° and 15°, with moderately deep soils needing more intensive conservation e.g. bench terracing, hexagon, miniconvertible terracing for the convenience of four wheel tractor farming. The conservation treatments can be done by medium sized machines such as Bulldozer D5 or D6.

C_3 Cultivable land 3, on slopes from 15° to 20°, needing bench terracing, hexagon, and miniconvertible terracing on deep soil and hillside ditching, individual basin on less deep soil. Mechanization is limited to small tractor or walking tractor because of the steepness of the slope. Terracing can be done by a smaller tractor with 8 ft wide blade.

C_4 Cultivable land 4, on slopes of 20° to 25°; all the necessary treatments are likely to be done by manual labor. Cultivation is to be practiced by walking tractor and hand labor.

P Pasture, improved and managed. Where slope approaches 25° and when the land is too wet, zero grazing should be practiced. Rotational grazing is recommended for all kinds of slopes.

FT Food trees or fruit trees. On slopes of 25° to 30°, orchard terracing is the main treatment supplemented with contour planting, diversion ditching, and mulching. Because of steepness of slopes, interspaces should be kept in permanent grass cover.

F Forest land, slopes over 30°, or over 25° where the soil is too shallow for any of the above soil conservation treatments.

(Continued)

Table 57. (Continued)

2. Any land which is too wet, occasionally flooded, or too stony, which prevents tillage and treatment, should be classified as:

(a) Below 25° -- Pasture
(b) Above 25° -- Forest

3. Gully dissected lands which prevent normal tillage activities--Forest.

4. Mapping Symbols: might be labeled as:

$\frac{\text{Most intensive use}}{\text{soil-slope-depth}}$

example: $\frac{C_2}{32 - 2 - D}$

means: $\frac{\text{Cultivable land 2}}{\text{Wirefence clay loam - 7° to 15° - 36 in}}$

Or, it could be simply labeled as C_2.

land husbandry which favor high productivity as well (Shaxon 1981). When supported by a realistic land capability classification, implementation of these concepts can provide a safeguard against severe soil erosion.

There are many ways to classify erosion control practices but for our purposes the primary breakdown will be into *traditional* for the localized methods employed largely in the LDCs and *developed* to indicate more universal practices.

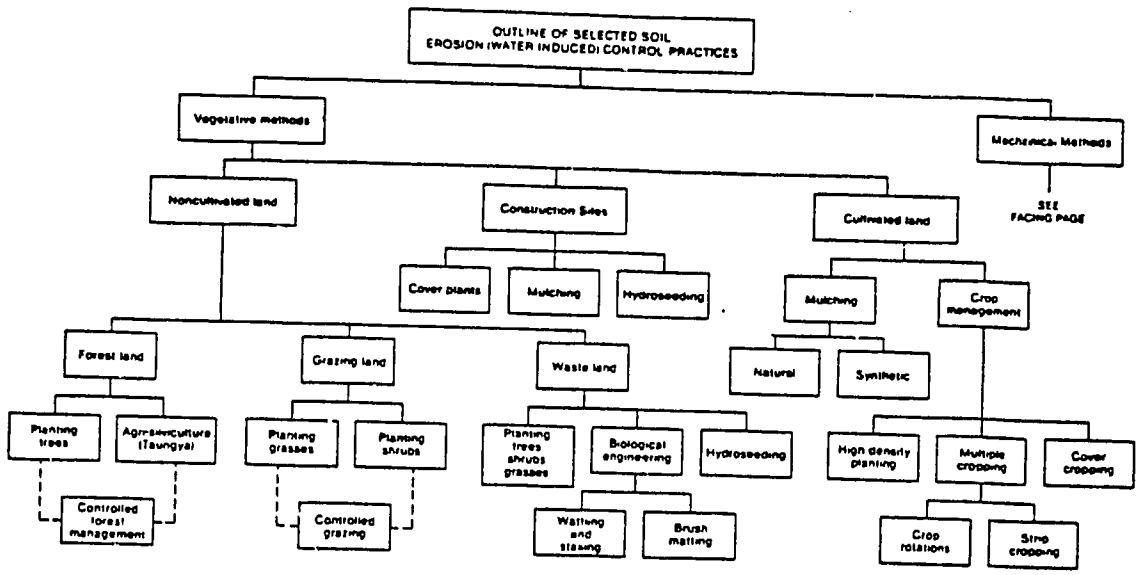
TRADITIONAL SYSTEMS

Some successful forms of erosion control are unique to certain areas. For example the "lock and spill" technique is traditional in Sri Lanka. In this method a fairly deep runoff storage ditch is constructed at the base of the field, with a berm placed downslope of the ditch. Runoff is stored in the basin and eventually evaporates or infiltrates into the soil. On pineapple plantations in Hawaii it is customary to position and secure large plastic sheets on small falls in the waterways to prevent undercutting and downcutting—a practice that works quite well as long as the gradient is not excessive. A seemingly clever erosion control practice in Ecuador has been reported verbally by Dr. D. Plucknett of the World Bank staff: Two bunds are constructed up and down slope. The area between is shaped into small ridges that wind in a serpentine manner down the hillside. Runoff water is thus confined laterally by the bunds and progresses relatively slowly downslope behind the barriers made across the slope by the ridges. Undoubtedly other erosion control procedures exist that are as yet generally unknown outside the country or area in which they are practiced. Such techniques represent a potentially valuable conservation resource and when recognized should be made more universally available. Sophisticated terracing systems have been built by early civilizations in many countries (e.g. in South America and the Philippines); many are still in use today.

DEVELOPED SYSTEMS

A number of erosion control practices are used throughout the world in developed countries and increasingly in LDCs (Fig. 30).

Vegetative measures (such as mulching, use of cover crops, strip-cropping, and the like) all favor maintenance of good rainfall infiltration into soil, whereas heavier mechanical operations (including land-shaping, construction of waterways, contour bunds, terraces, or ridges) are based on reducing topographic hazards and safe removal of runoff. Both have feasibility limits. Very often, application of both kinds of measures is necessary for a sound conservation program (Lal 1977*b* and 1981). In the following pages various erosion control measures will be discussed in broad terms. Specifications and detailed design criteria may be obtained from pertinent technical sources such as the Soil Conservation Service (1975*a*), publications of the Food and Agricultural Organization of the United Nations,



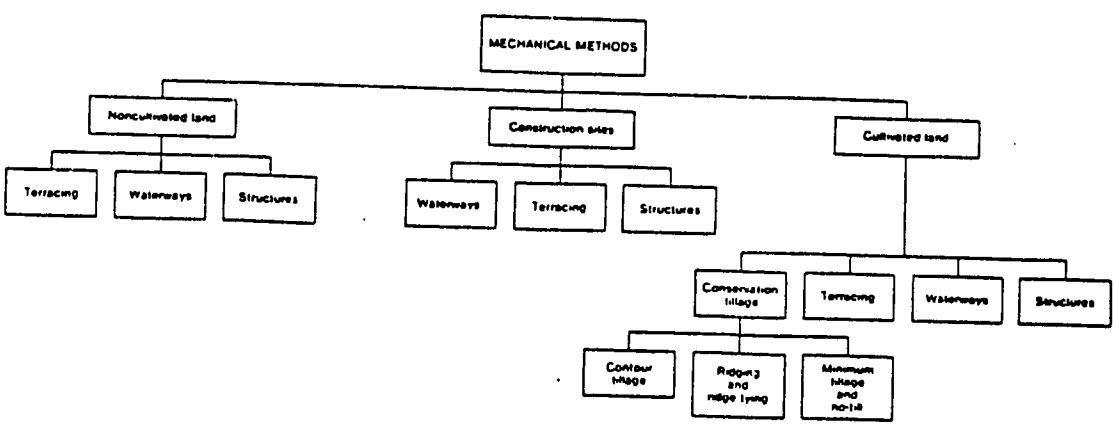


Figure 30. Flow chart of selected soil erosion practices for water-induced soil erosion.

other engineering manuals (Hudson 1975; Beasley 1972), the Manual of Reforestation and Erosion Control for the Philippines (Weidelt 1975), and/or from experienced field conservationists. The problems and practice of soil conservation were the subject of a recent conference and subsequent published proceedings (ICSC 1981).

Vegetative Control Methods

Vegetation is the key to the prevention of soil erosion (see chapters 2 and 4). If all soils were perpetually covered with mature forests or grass sward, accelerated erosion would not be a problem. However, at least for brief periods of time, farming, logging, fires, mining, and construction activities expose the soil, which then becomes vulnerable to erosive rainfall and runoff. In Table 58 are listed all the plant species discussed in this chapter as well as others, that have been found useful for erosion control.

Nonculturated Lands

Forest Land. Several attributes of natural forest vegetation are responsible for the effectiveness of forests in protecting the soil against erosion. In the humid tropics these include the appreciable soil protection by the canopy and undergrowth, little soil exposure due to abundant litter and minimum disturbance, beneficial soil binding by highly proliferated roots and decomposed organic matter, and the frequently significant activity associated with the presence of earthworms or other soil fauna. Coupled with the high evapotranspiration demand of forest vegetation, these attributes can minimize soil detachment and maximize infiltration rates thus providing restricted runoff and erosion (e.g. Lal 1980, Sanchez 1976).

Verduzco (1960) recommended that each country keep at least 25 percent of its land area in forests. This general statement was prompted by the occurrence of floods, droughts, dust storms, erosion, and sudden temperature changes in Mexico following the destruction of forests in that country. In light of the Mexican experience, it is unfortunate that herbicides were used to defoliate and thus destroy large areas of jungle in South Vietnam (Maher 1972). Interestingly, however, Bedewski (1956) claimed that there is no evidence to uphold the belief that a soil may become too poor to support forest regrowth in tropical regions.

The illustrations that follow show how some developing countries have incorporated tree planting in reforestation or afforestation programs intended primarily to curtail or correct erosion problems.

EXAMPLE 1—INDIA: Afforestation of a badly eroded and gullied 272 ha area at Rehmankhera has been reported (Jalote and Malik 1974). Initially fencing was installed to keep livestock out. Then contour trenches 180 by 60 by 45 cm deep were dug, in which seeds of *Dalbergia sissoo, Acacia nilotica, Acacia catechu, Ailanthus excelsa,* and *Albizia lebbek* were sown. Nursery transplants supplemented the seeding. The project was started in 1951-1952 and reforestation was completed in 1964. Today complete cover exists and the soil is well protected.

EXAMPLE 2—MALAGASY REPUBLIC: Reforestation of degraded lands is ongoing in the Malagasy Republic (Madagascar). Various *Eucalyptus* species are favored and 130,000 ha of high land have been planted with these fast growing trees. Pine plantations have been established on 16,000 ha, three quarters of which are located in the Matsiatra Valley. In addition 4000 ha of land around Lake Alaotra have been sown from the air with *Mimosa* spp., Dingadingana (scientific name unavailable), and others to protect the watersheds (Le Bourdiec 1972).

EXAMPLE 3—THE PHILIPPINES: Different objectives may have governed the planting of forests in the Philippines. Only eight species of sawtimber are recommended, as too many species were presumed to cause marketing problems. The eight are large leaf mahogany *(Swietenia macrophylla),* teak *(Tectona grandis),* benguet pine *(Pinus insularis),* narra *(Pterocarpus indicus),* prickly narra *(Pterocarpus vidalianus),* melina *(Gmelina arborea),* kariskis *(Albizia falcataria),* and bagras *(Eucalyptus deglupta).* Four of these species—benguet pine, melina, kariskis, and bagras—are also recommended for pulpwood plantings. Ipil-ipil *(Leucaena leucocephala)* is the commonest fuelwood in plantations, although kakawati *(Gliricidia sepium)* and Cassia siamea are also planted for this purpose (Weidelt 1975).

EXAMPLE 4—BOLIVIA: In South America, Chase (1976) has suggested that algaroba *(Prosopis* spp.), carob *(Ceratonia siliqua)* and honey locust *(Gleditsia triacanthos)* be used for forest farming in Bolivia. All bear pods that contain 16-21 percent protein and the meal is an excellent food source for cattle and suitable for human consumption as well. Their ex-

Table 58. Selected vegetation useful for erosion control*

Acacia catechu	Acacia, Catechu, Cutch tree, Khair
Acacia decurrens	Black, silver, or green wattle
Acacia mangium	N.A.†
Acacia nilotica	Acacia, gumarabic, babul, suntwood
Acacia tortilis	Gum-akazia
Acioa barteri	N.A.
Aeschynomene indica	Joint vetch
Agave cantala	Maguey
Ailanthus excelsa	Ailanthus
Albizia falcataria	Kariskis
Albizia lebbek	Woman's tongue tree, Lebbek tree, Siris tree
Alnus maritima	Japanese alder
Alternanthera brasiliana	Racaba
Alysicarpus rugosus	Alyce clover
Arachis hypogaea	Groundnut, peanut
Arundinella nepalensis	N.A.
Astragalus garbancillo	Milkvetch
Avena sativa	Oats
Axonopus compressus	Carpet grass
Bambusa spinosa	Bamboo, Kawayan
Bambusa vulgaris	Bamboo, Kawayan-Kiling
Bothriochloa intermedia	Australian bluestem
Brachiaria decumbens	N.A.
Bromus spp.	Brome grass
Broussonetia papyrifera	Paper mulberry
Cajanus cajan	Arhar, pigeon pea, Congo pea, etc.
Calamagrostis spp.	Reed grass
Calliandra callothyrsus	N.A.
Calligonum spp.	Calligon
Calopogonium caeruleum	Calopogonium, Jicuma
Calopogonium mucunoides	Calopo, Calopogonium, Katjang asoe
Cassia hookeriana	Shower tree
Cassia siamea	Kassod tree
Cenchrus ciliaris	Sandbur
Cenchrus sitigerus	Sandbur
Centrosema pubescens	Peaflower
Ceratonia siliqua	Carob
Chloris barbata	Chloris
Chloris bournei	Chloris
Chloris guyana	Rhodesgrass
Coffea spp.	Coffee
Crotolaria spp.	Crotolaria
Cymbopogon coloratus	N.A.
Cynodon dactylon	Bermuda grass
Cynodon plectostachyum	Stargrass
Dactylis glomerata	Cocksfoot, orchard grass
Dalbergia sissoo	Sissoo
Datura alba	Trumpet tree
Dendrocalamus strictus	Male bamboo, Calcutta bamboo, bans, etc.
Desmodium diffusum	Desmodium, tick clover, beggar weed
Desmodium intortum	Desmodium, tick clover, beggar weed
Desmodium uncinatum	Spanish clover
Dichanthium annulatum	N.A.
Digitaria decumbens	Pangola grass
Dolichos lablab	Hyacinth bean, lablab

(Continued)

Table 58. (Continued)

Eragrostis curvula	-- Weeping love grass
Erigeron mucronatum	-- Australian daisy
Eucalyptus deglupta	-- Bagras
Eucalyptus spp.	-- Eucalyptus
Ficus nota	-- Tibig
Gleditsia triacanthos	-- Honey locust
Gliricidia sepium	-- Madre de cacao, kakawati, Nicaraguan cocoa shade
Gmelina arborea	-- Melina
Glycine Max	-- Soybean
Halaxylon persicum	-- N.A.
Helianthus tuberosus	-- Mexican sunflower, girasole, Jerusalem artichoke
Homonota riparia	-- Dumanay
Indigofera endecaphylla	-- Creeping indigo
Lagerstroemea subcostata	-- N.A.
Lantana camara	-- Yellow sage
Lasiurus sindicus	-- N.A.
Lespedeza cuneata	-- Lespedeza
Leucaena leucocephala	-- Uaxin, koa haole, ipil-ipil, lamtoro
Lolium perenne	-- Perennial ryegrass
Lupinus spp.	-- Lupin
Macroptilium atropurpureum	-- Siratro
Mallotus japonicus	-- N.A.
Medicago sativa	-- Lucerne, alfalfa
Mimosa spp.	-- Mimosa
Mucuna cochinchinensis	-- Velvet bean
Mucuna nigricans	-- Lipai
Musa sapientum	-- Banana
Nauclea spp.	-- Sarcocephalus, fathead tree, West African boxwood, bengal perampocan
Neomarica northiana	-- Apostle plant
Panicum maximum	-- Guinea grass
Panicum turgidum	-- Panicum
Paspalum notatum	-- Bahia grass
Pennisetum clandestinum	-- Kikuyu grass
Pennisetum pedicellatum	-- Pennisetum
Pennisetum polystachyon	-- Thin Napier grass
Pennisetum purpureum	-- Elephant grass, Napier grass
Phalaris tuberosa	-- Large canary grass
Phaseolus mungo	-- Urd, black gram
Phaseolus radiatus	-- Muong, mung bean, green gram
Pinus caribaea	-- Cuban pine, Carib pine, slash pine
Pinus insularis	-- Benguet pine
Pinus palustris	-- Longleaf pine
Pinus patula	-- Tropical pine, Mexican yellow pine
Pinus rigida	-- Pitch pine
Pinus taeda	-- Loblolly pine
Pithecolobium dulce	-- Kamachile, manella, tamarind, opiuma
Populus balsamifera	-- Cottonwood
Prosopsis juliflora	-- Common mesquite, algaroba
Pterocarpus indicus	-- Narra, padauk, Burmese rosewood
Pterocarpus vidalianus	-- Prickly narra
Pueraria javanica	-- Kudzu
Pueraria phaseoloides	-- Tropical kudzu

(Continued)

Table 58. (Continued)

Pueraria thunbergiana	-- Kudzu vine
Rhynchosia minima	-- N.A.
Robinia pseudoacacia	-- Black locust
Salix spp.	-- Willow
Sansevieria guineensis	-- Sword plant, African bowstring hemp
Sansevieria zeylanica	-- Ceylon bowstring
Schizostachyum lumampao	-- Boho
Sesbania grandiflora	-- Agati, bacule, turi, etc.
Setaria splendida	-- Bristle grass
Sorghum spp.	-- Sorghum
Stizolobium deerangiana (Mucuna deerangiana)	-- Velvet bean
Stylosanthes gracilis	-- Stylosanthes
Stylosanthes guayanensis	-- Stylosanthes, Brazilian lucerne
Stylosanthes humilis	-- Stylosanthes
Swietenia macrophylla	-- Large leaf mahogany, Honduras mahogany
Tamarix aphylla	-- Tamarisk
Tecomella undulata	-- Marwak teak
Tectona grandis	-- Teak
Tephrosia candida	-- White tephrosia
Teramnus labialis	-- N.A.
Thea sinensis	-- Tea
Trifolium pratense	-- Red clover
Trifolium repens	-- White clover
Tripsacum laxum	-- Guatemala gamagrass, yerba Guatemala
Triticum aestivum	-- Wheat
Urochloa Mosambicensis	-- Buffel grass
Wedelia spp.	-- Wedelia
Zea mays	-- Corn, maize

Source: Bunting and Milsum 1928; FAO 1977b; NAS 1979; RRIM 1977; Shankarnarayan and Hagoon 1974; Weldelt 1975; and others.
*Many species are of greatest value when planted in combination with other species.
†N.A. - not available.

tablishment was encouraged since all are legumes (thus able to fix nitrogen), drought resistant, and able to fruit for a hundred years.

EXAMPLE 5—CARIBBEAN ISLANDS AND MEXICO: Development of plantation forestry is a major thrust in the government of Jamaica's watershed program. The favored species is *Pinus caribaea* (Carib pine), which is being used to restore eroded uplands and to ensure regular stream flow (Sheng and Stennett 1975). For Trinidad and Tobago, measures recommended to curtail the erosion caused by burning and shifting cultivation have been to establish such crops as limes and tonka beans at the 500 to 800 ft levels and to allow areas above 800 ft to revert to natural forest (Hardy 1942). Living fence rows (primarily willows, and cottonwoods) protect the land in Rio San Miguel, Mexico from eroding floodwaters. The living fences also serve to trap silt from the floodwaters on adjacent fields (Nabhan and Sheridan 1977).

The role of *Leucaena leucocephala* in the tropics is rapidly expanding (NAS 1977). Beside its widespread use for firewood it has value as a windbreak, as a firebreak, for charcoal manufacture, for forage, as a fertilizer source, for wood and pulp—and the apparent ability to compete successfully with cogon (*Imperata cylindrica*). For example, on the island of Flores in Indonesia, where it is termed *lamtoro*, 10,000 ha of volcanic slopes in danger of erosion have been planted with Leucaena and 20,000 ha more were planned over the next four years (Metzner 1976). Leucaena is also being considered in the dry monsoonal areas of the Northern Territory of Australia (Walter 1971). Other rapidly growing

leguminous tropical trees have great value. *Albizia falcata ia* (called a miracle tree because of its exceptionally rapid growth), *Sesbania grandiflora* (forage, fuelwood, paper pulp, etc.), *Calliandra calothyrsus* (fuelwood, firebreaks, eradication of Imperata grass) and *Acacia mangium* (exceptional performance on poor sites) are among those advocated (NAS 1979).

To optimize land cultivation while at the same time preserving the valuable role of trees in hilly areas, agri-silviculture (the *taungya* system) is being used by forestry departments in some developing countries. In one form, the forest is felled and cleared by a group of farmers who then plant crops in the area. Trees are planted among the crops by forestry department personnel and the seedlings are tended by the farmers, along with their crops, for approximately two years. Subsequently, shade from the trees is enough to prevent further crop growth and the farmers are assigned new locations nearby in the forest. However, the farmers return to the old location to tend the tree crop until it can survive without care (Tempany and Grist 1958). Seventy-nine woody species and 42 agricultural crops have been listed as used in this system in the tropics (King, cited by Roche 1974). For example, taro, sweet potato, cassava, maize, and upland rice are suggested as agricultural crops to be grown in the Philippines under the *taungya* system; however banana, plantain, cassava, maize, sugarcane, rice, tobacco, and yams are not tolerated by forestry officials in some countries.

This is only one example of successful utilization of forest land with apparently minimal degradation. Similar precautions are needed whenever disturbances to natural forest are brought about by other activities such as logging and mining.

Grazing Land. A problem of great concern in developing countries is the management of livestock. The destruction of grassland by overgrazing in North Africa for example is estimated to be 100,000 ha a year (Le Houerou, cited by Semple 1971). Other examples of destructive grazing in semiarid regions have been reviewed in chapter 2. Brown (1971) speculated that cultivation can support three times the present 50 million pastoralists in Africa and suggested that these pastoralists be converted to cultivators in areas of more than 250 mm annual rainfall or where irrigation can be made available. He indicated that if such a plan cannot be worked out satisfactorily it is imperative that herd sizes be reduced. Young calves can be sent to fattening areas to reduce the load on the land. Sale of one animal enables pastoralists to feed their families on grain for six months. Semple (1971) observed, however, that destocking is not easily done because of the cultural and social values placed upon large herds, regardless of the physical condition of the animals. This latter observation was supported by Hudson (1981). Semple suggested that legumes be fostered by deferred grazing periods and by a seeding program using *Stylosanthes* spp. and *Desmodium* spp. Planned and prescribed burning was also recommended to convert worthless brushland to grassland and wooded savannahs.

Stocking rates must be realistically determined with view of both animal requirements and land capability for producing the specific pasture under consideration (Blandford 1981 and Blair-Rains 1981). Therefore, no universal formula can be given for conservation-minded use of grazing land. Harrington and Pratchett (1974), for example, suggested specific stocking rates for Ankole, Uganda, at approximately 1.1 ha per adult animal. This rate applies to rangeland largely under *Brachiaria decumbens* with unpalatable *Cymbopogon afionardus* removed (Harrington and Pratchett 1974).

Wasteland. On eroded slopes and gullies various forms of vegetative controls may be employed. The straightforward technique of planting trees, shrubs, and grasses, usually in mixtures, is one approach when the terrain is not too steep. However, as steepness increases it may be necessary to use more radical measures such as biological engineering (Figs 31, 32). Examples of this are the various forms of brush matting or brush cover techniques. In one method sprouting or unsprouted pegs are driven in along the contour to about 20 cm deep. Sprouting brushwood is spread over the slope, butt (thicker) ends downslope, leaving no uncovered areas. The pegs are then connected with wire and driven further into the ground, pressing the brushwood firmly to the ground. A modification of brush matting is for the brushwood to be placed on small platforms or benches on the slope with the wood covered by soil from the adjacent uphill bench. Fertilizer is mixed in as well (Weidelt 1975). According to Weidelt the brush matting method, in one of its many forms, is probably the most stable of all live structures and is recommended for steep slopes, unstable soils, and

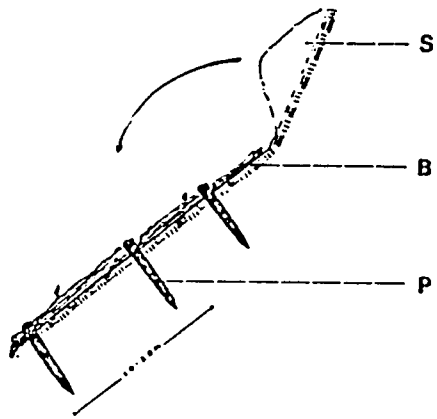


Figure 31. The brush matting technique. S = soil; B = brushwood; P = peg. (Weidelt 1975)

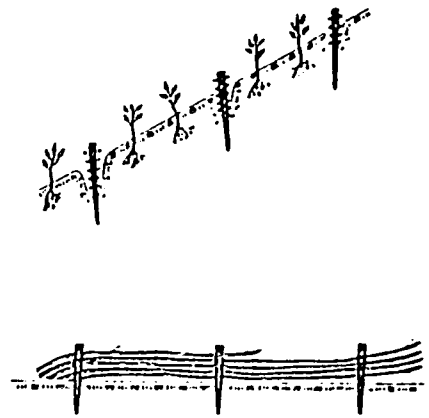


Figure 32. The wattling and staking technique. a. Cross section; b. side view. (Weidelt 1975)

high intensity rainfall areas such as the typhoon belt in the Philippines.

Another form of biological engineering is the wattling and staking method (Sheng 1977*b*; Weidelt 1975). It is used, for example, on road-fill banks and slopes in Jamaica and the Philippines. The technique used in the Philippines requires shallow trenches with stakes driven into the trenches about 50 to 70 cm apart. Wattling consists of straight rods from such plants as Leucaena or sunflower interwoven between the stakes with the butt ends of the rods bent into or covered with soil. As practiced in Jamaica, this method is more like the brush matting technique. In either case, however, grasses or trees may be planted in the bare areas between the wattles.

Hydroseeding or hydromulching is another form of vegetative control that has gained considerable popularity in the past decade. A slurry or suspension is prepared of seeds and/or stolons of grasses, plus a mulch or binder, fertilizer, and water. Application of the suspension on bare slopes can be done from back sprayers or tank trucks. Weidelt (1975) has reported that even inaccessible areas in Japan have been hydroseeded successfully from helicopters. In any case a grass cover is provided to slopes both quickly and conveniently. This technique is widely used for stabilizing road cuts in the United States, Europe, and Australia.

Cultivated Lands

Erosion control on croplands needs special emphasis as these are the lands with the most potential for alleviating food scarcities in developing countries. The effects of cover and agricultural management have been discussed in chapter 4 under the C and P factors. Although these effects are closely interrelated and difficult to evaluate independently (Wischmeier and Smith 1978), implementation of sound practices is a powerful tool for minimizing accelerated soil erosion.

Use of Cover Crops. At the risk of being repetitious it is emphasized again that maintaining adequate cover is probably the best means of minimizing or preventing soil erosion. For example, at Dehra Dun, north India, Patnaik (1975) found specific losses of 42 Tm/ha under 1250 mm of natural rainfall (June to October) on bare fallow soil with 9 percent slope. Under the same conditions, natural grass cover reduced soil losses to 1 Tm/ha. In addition to protecting against erosion, cover crops smother weeds and may be incorporated into the soil as green manure (Constantinescu 1976). Their importance increases when the primary crop is slow growing or planted at low density. The effectiveness of cover crops depends on such factors as density of foliage; root growth characteristics; water retention,

depletion, and penetration; soil fertility; and so on (Sharma et al. 1976). Some examples follow to illustrate the use of cover crops for erosion control in various tropical countries.

In rubber and oil palm plantations of Sumatra and Java, *Calopogonium mucunoides* has been used for over fifty years as protective cover on newly planted plantations (Milsum and Cutler 1925). Other legumes used are *Centrosema pubescens* and *Pueraria phaseoloides*. Cover plants have been classified into two groups. One includes the low-growing type suitable for direct control of splash and sheet wash such as *Calopogonium mucunoides, Centrosema pubescens, Indigofera endecaphylla*, and *Pueraria phaseoloides*, to name a few. The other group is composed of erect-growing types that are more suitable for green manures, including *Tephrosia candida* and *Crotalaria anagyroides* (Bunting and Milsum 1928). *Mucuna cochinchinensis* has great promise according to ongoing experiments in Malaysia.[1] It grows faster and more vigorously than conventional legume covers such as *Calopogonium mucunoides, Calopogonium caeruleum, Centrosema pubescens*, and *Pueraria phaseoloides*. However, Mucuna fades out in 8 to 10 months so that it is necessary simultaneously to plant *Pueraria phaseoloides* or *Calopogonium caeruleum* in addition, to take over when Mucuna withers and dies (RRIM 1977). The free rooting perennial herb, *Alternanthera brasiliana*, which is propagated by cuttings, is highly recommended as a ground cover on the edges of large terraces of oil palm plantings in Malaysia (Duckett and Tan 1974). Newly planted stands of rubber trees are vulnerable to soil loss until the canopy closes after five years of growth. A comparative study of several forms of cover vegetation, including legumes and a grass, was made on an immature stand of rubber trees in Malaysia (see Table 59). The amount of soil deposited on the terraces from the inter-rows, which had various covers, was used as an indication of the efficiency of each cover practice for erosion control. It is noted that *Calopogonium* was twice as efficient in preventing soil loss as *Pueraria*, and over three times as effective as bare soil. In Verma's (1968) assessment of the value of the protective canopy provided by several common Indian legumes, moong (*Phaseolus radiatus*) provided good early cover and protected the soil from the high-intensity July rains. Similarly, it was found in Guaiba RS, Brazil that soybeans (*Glycine max*) gave better protective cover than wheat (*Triticum aestivum*) (Eira et al. 1977).

Multiple Cropping. Multiple cropping is an agronomic practice that is both highly productive and soil conserving. Whether it takes the form of sequential cropping that limits the bare fallow time between crops, or inter-row cropping that limits the spatial extent of bare soil within a field, the result is the same. At any given time, cover absorbs the forces of raindrop impact and slows down runoff. For example, an erosion-vulnerable period of three to five years exists in tea plantations from the time of felling and clearing the old trees until the newly planted trees develop a complete canopy. During this period mulching or inter-row planting of oats is recommended in East Africa (Othieno 1975). A beneficial form of cover/mixed cropping used in the coffee-growing areas of East Africa is to grow bananas and coffee together. The banana plants provide shade to the coffee and the fallen leaves of the former serve as an anti-erosion mulch (Constantinesco 1976). Studies in Kanpur, India (Sharma et al. 1976) indicated that a pure crop of urd (*Phaseolus mungo*) and a mixture of arhar (*Cajanus cajan*) and groundnut (*Arachis hypogaea*) were most effective for controlling splash erosion among the crops studied, which also included maize, sorghum, guar, and soybeans. Soybeans controlled sheet erosion well in orange groves in Minas Gerais, Brazil; however, tree growth and fruit yield decreased because of the competition (Pacheco et al. 1975).

Among the important practices recommended in the Philippines is that citrus orchards should be interplanted with cover crops. For example, in the provinces of Batangas and Camarines Sur, citrus groves are planted to the legumes, *Calopogonium caeruleum*, and *Pueraria javanica* (tropical kudzu). Ipil-ipil and Madre de cacao are also used as cover crops in Batangas. When the plants are about a meter high they are cut back to about 80 cm and the trimmings are allowed to fall to the ground, thus supplying nutrients and reducing soil loss (Hernandez n.d.).

Strip-cropping is a means of "dividing land into alternate strips of close growing, erosion resistant plants such as grass, grass/legume mixtures, small grains, or natural vegetation with strips of wider spaced crops such as maize, sorghums, cotton and root crops" (Constantinesco 1976). Almost invariably the practice is done across the slope, that is, on the contour. An indication of the success of the technique may be obtained from Table 60 in which soil losses are compared between cotton and cotton planted in strips with soybeans and soybeans/stubble. Soil losses were always greater for cotton alone and the effectiveness of strip-cropping in reducing soil loss increased with greater slopes. This form of multiple cropping may be applied in several ways. For example, rotational field strip-cropping is used successfully with alternate arable strips and grassland. Fertility status is favorably maintained as well when the arable crop is rotated with the grass. Buffer strip-cropping is another form in which permanent strips of grass, rarely more than 1.2 to 3 m wide, are left between cultivated areas (Constantinesco 1976). Figure 33 illustrates some of the alternatives of strip-cropping.

Crop rotation, as a form of multiple cropping, is an established method of maintaining soil fertility and reducing erosion. A grass or grass/legume mixture (ground cover) alternated in time between an annual crop such as maize will provide the soil with excellent cover as well as fertility when the residues are plowed under. Apart from the protection provided by the ground cover, the annual crop will provide a denser, more thrifty stand by restoring fertility to the soil. It will thus increase soil coverage, thereby limiting erosion.

Shifting cultivation is the earliest and simplest form of rotation used by humans (see chap. 4). A "short" period of cultivation is followed by a "long" period of fallow. As fallow periods become shortened, it has been suggested that use of specialized crops between annual crops will prevent soil deterioration. "Experiments in Africa using star-

Table 59. Comparison of effect of vegetative covers in reducing erosion in Malaysia over a 20-month period

Cover spp.	Soil deposited on terraces (cm)
Calopogonium	5.64
Pueraria	11.07
Crotolaria	15.69
Tephrosia	14.02
Grasses	12.67
Bare	19.04

Source: RRIM 1977.
Rainfall data were not reported.

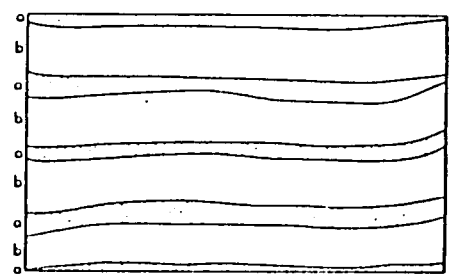


Figure 33. Generalized diagram of strip cropping. a = grass or grass/legume; b = maize, sorghum, cotton, or root crops. (Modified from Constantinesco 1976)

Table 60. Seasonal soil loss from Cecil clay loam (Alabama) planted to cotton and to cotton strip-cropped with soybeans

	Rainfall (cm)	Cropping System	Soil loss (Tm/ha) Slope (%) 5	10	15	20
Early summer	35.43	cotton alone	7.82	15.85	57.37	53.04
		cotton, soybean strips	6.18	8.43	12.72	16.21
Late summer & fall	21.64	cotton alone	2.78	3.16	13.56	16.55
		cotton, soybean-stubble strips	2.35	2.47	3.77	4.41
Entire growing season	57.07	cotton alone	10.59	19.00	70.91	69.59
		cotton, soybean strips	8.53	10.90	16.83	20.63

Source: Modified from Bennett 1939: 349.

1 William Broughton, then of the University of Malaysia, Kuala Lumpur. Personal communication, 6 June 1978.

grass (*Cynodon plectostachyum*), elephant grass (*Pennisetum purpureum*) and weeping lovegrass (*Eragrostis curvula*) in rotation with maize, tobacco, and forage crops suggest that the residual benefit of the grass ley is best in the first year" (Constantinesco 1976), by the third year, when the grass is plowed in, there are no benefits. Rotations planned for erosion control should be short, with quick changes from cash to forage crop and back again. For example the best alternative rotations for growing tobacco in Zimbabwe are one year of weeping lovegrass followed by two years of tobacco or two years of grass and four years of tobacco. Both have the same crop-to-grass ratio but soil loss averaged 12 Tm/ha/yr in the first rotation and 14.75 Tm/ha/yr during the longer rotation (Hudson 1971).

High Density Planting A very effective way to improve the cover is to increase the density of the planted crop. For example, Hudson (1971) has shown that maize grown in Central Africa at 25,000 plants/ha (0.4 m apart in 1 m rows) lost 12.3 Tm/ha of soil in one year. When the plant population was increased to 37,000/ha (0.27 m apart in 1 m rows) annual soil loss was only 0.7 Tm/ha (Table 61). Of course, with the increased plant density, necessary adjustments in management, such as fertilizer additions, are required. There is also a density limit above which competition between plants limits production severely. Overall, implementation of good agronomic practices will reduce soil losses and must be considered as an integral component of the strategy for effective soil conservation (Shaxson 1981). It has been said that if all maize grown in Africa were produced at an average yield of 5 tons/ha rather than about 1 ton/ha as at present, then half the erosion problems of the continent would disappear (Hudson 1971).

Mulching Mulching is an important erosion control technique, especially on cultivated lands and construction sites. Mulch is a natural or artificial layer of plant residue or other material, such as sand, gravel, or paper, covering the soil surface (SCSA 1976). The mulch material takes many forms—from unused plant remains, wood shavings, and jute netting to bitumen, plastics, and chemical sprays. Its greatest protective value is manifested when the land would otherwise be left bare, that is, after harvesting, before planting, and during early stages of crop growth.

Frequently used natural mulches in the humid tropics are sugarcane bagasse, banana leaves, coconut fronds, and straw from grain crops. Mulches absorb the direct impact of raindrops and thereby minimize soil detachment by raindrop splash. In addition runoff is slowed down and losses are reduced because the infiltration rate of the soil is maintained at its maximum level (Lal 1975). Some workers suggested that mulching enhances the activity of earthworms in soils. Table 62 shows the effect of mulching on earthworm populations in Nigeria. Earthworms improve soil permeability and allow high infiltration rates to be maintained.

The benefits of mulching for reducing soil losses are well established and were discussed in chapter 1. Some evidence that confirms these benefits exists in the tropics. At Apiodoume, Ivory Coast, West Africa, two plots were observed by Roose (1975*b*); one was a natural rainforest, the other a banana planting that was mulched with straw from Guatemala grass (*Tripsacum laxum*) at 20 Tm/ha. Measured soil loss, at 0.1 Tm/ha/yr, was essentially the same under both conditions. Another example of the value of mulching in preventing soil loss is evident from Table 63, where unmulched plots always lost more sediment than their mulched counterparts.

Although mulch material may be transported from one site and applied elsewhere this is an expensive and time-consuming process. Such a procedure may be used in labor-intensive situations, but agriculturally it is generally easier to grow a live source of mulch in which the desired crop is planted in strips opened by tillage or use of herbicides. Experiments with *Stylosanthes gracilis* and maize in Nigeria (Lal 1975) showed that this combination is effective for erosion control, but that the former aggressively competes with the latter for available water. Perennial crops in Uganda, such as bananas and coffee, are generally mulched, and banana mulch is used on coffee plantations in Tanzania (Ahn 1977).

Mulch farming is not equally successful when used under different climatic zones or farming systems (Lal 1981). A problem with mulch farming is that it is difficult to prepare the seedbed for the following crop with mulch on the ground. Herbicide management will allow such a preparation to take place under cultivation with reduced tillage. Disc harrowing will incorporate some of the mulch with the soil, but in many developing countries where animal-drawn machinery is used, the technique is unpopular with farmers, although it should be encouraged (Constantinesco 1976). Other frequently encountered problems are the excessive rates of residue decomposition in certain regions and the tendency to enhance the proliferation of pathogens in others (Hatch 1981).

Construction Sites

Construction sites, including highways and urban developments, are particularly prone to heavy soil losses unless great care is taken. In most countries official soil conservation agencies have been established to help the developer and homeowner as well as the farmer. Direct consultation is usually available to the builder, in addition to written information such as leaflets and bulletins on minimizing soil loss. For example, the following recommendations were made for construction activities in Hawaii, and generally apply elsewhere (SCS 1971).

1. Preparation of a ground plan for the outside is as necessary as a floor plan for the inside.
2. Buildings should be planned to conform to natural topography in order to minimize grading.
3. Disturb only the construction area. Do not clear an extended area unless construction will start immediately on the whole area.
4. Protect trees and shrubs that are to be retained.
5. Stockpile and save topsoil for final grading of the lawn area.
6. Protect the bare soil during construction.
   a. Complete driveways, grading, and sodding as quickly as possible.
   b. Protect bare areas, such as stockpiles, with mulch. Sugarcane bagasse spread 2 inches deep and secured with fiber netting is excellent.

Table 61. The effect of crop management on soil and water losses from maize in Zimbabwe

	Plot A Medium production level	Plot B High production level
Plant population	25,000 plants/ha	37,000 plants/ha
Rainfall	1130 mm	1130 mm
Fertilizer application	N 20kg/ha; P_2O_5 50kg/ha	N 100kg/ha; P_2O_5 80kg/ha
Crop residues	Removed	Plowed in
Crop yield	5 ton/ha	10 ton/ha
Runoff	250 mm	20 mm
Soil loss	12.3 ton/ha	0.7 ton/ha

Source: Modified from Hudson 1971: 199.

Table 62. Effect of mulching on earthworm casts in maize in Nigeria

Treatment	Worm casts/m^2	Equivalent weight of casts (tons/ha)
Mulched	568	127
Inter-row mulch	264	59
Unmulched	56	13

Source: Modified from Lal 1975.

Table 63. Effect of mulching in Nigeria on sediment density in runoff water under maize

Slope (%)	Sediment density (g/l) Unmulched	Mulched
1	0.28	0.00
5	9.76	0.36
10	7.00	0.45
15	5.75	0.08

Source: Lal 1975.

c. If stockpiles or rough-graded areas are to be exposed for several months, seed with ryegrass as temporary cover and irrigate if necessary for establishment.

7. Control runoff water with temporary diversions and silt traps.

8. Finally, remove all debris and grade to provide adequate drainage. Then prepare the seedbed, fertilize, and establish permanent vegetation. When seeded, erodible areas should be mulched.

Cover plants recommended (SCS 1976) for use on construction sites in Hawaii are Bahia grass, Bermuda grass, Buffelgrass, pangola grass, Kikuyu grass, oats, ryegrass, Lippia, Waipahu fig and Wedelia. Most of these probably thrive throughout the tropics. The mulching materials recommended by the SCS (1976) for Hawaii are sugarcane bagasse, pineapple trash, sawdust, and planar shavings. On steep slopes or under strong wind conditions, these must be anchored with asphalt spray or jute netting. Use of hydroseeding is common on steep slopes of both building sites and road banks. European countries are rapidly accepting soil conditioners to stabilize slopes (De Boodt 1975), but Roose (1975b) in the same publication, stated that straw (< 10 Tm/ha) will protect roadbanks effectively against erosion. In Malaysia, Soong and Yeoh (1975) found that latex-oil emulsions sprayed on highly erodible exposed soil surfaces reduced soil losses by 80 to 87 percent during the monsoon season, compared with untreated soil. Latex oil is a by-product of the rubber industry. Incorporation of grass seeds (*Axonopus compressus*) with the emulsion caused a reduction of 93 percent in soil losses in comparison with the untreated soil surface.

Mechanical Control Methods

Above certain limits—particularly those related to topography—the vegetative or biological methods of erosion control discussed earlier may not be effective on their own. Although it is difficult to generalize about the slope limits for vegetative control methods, Sheng (1979) has stated that grass barrier plots on 17° slopes in El Salvador were ineffective (producing a soil loss of 124 Tm/ha) as was the case in Taiwan on 18° slopes. It is important to recognize that the limits that necessitate supplementary mechanical control measures are generally dictated by prevailing slope and land use. The remainder of this chapter will describe the so-called mechanical techniques of control, most of which originated in the West (Moldenhauer and Foster 1981; Meyer 1981; Chisci 1981) and have been tried in some developing countries in the tropics (Hurni 1981; Barber et al. 1981; Bonsu 1981). Most generally these techniques involve soil and land manipulation, either manually or by machinery, and sometimes the use of various fabricated structures.

Conservation Tillage

Minimum Tillage. For many years the conventional tillage operations used in intensive agriculture in developed countries have been plowing, discing, planting, and cultivating. More recently, in response to environmental pressures and oil shortages, the concept of minimum tillage has evolved; this does not define a specific system of tillage, but refers to any system of tillage with fewer operations than the conventional one (Wittmus et al. 1973). The most radical is the no-tillage (no-till) system, in which the only soil manipulation is to open a trench or slot in the sod of the existing vegetation. The trench must be wide enough to receive the seeds or root of the transplant and to provide seed or root coverage. Weeds are controlled by herbicides, crop rotation, and/or plant competition (Young 1973). The ultimate in row crop production in the United States is continuous no-till corn culture with three tons of residue on the surface. This practice is nearly as effective as permanent grass for water or wind erosion control (Wittmus et al. 1973). Minimum tillage may approximate rather closely the conditions found in several traditional tropical cropping systems such as shifting cultivation and rudimentary sedentary tillage.

Recent data from Brazil compared conventional and no-till cultivation on three successive corn crops on two soils (Benatti et al. 1977). On the Latosol Roxo soil, erosional losses were 20 percent lower from the no-till than the conventional plot, on the podzolized Lins and Marilia plots, no-till controlled 63 percent of soil losses compared to conventional tillage. The corn grain production was similar or smaller in the no-till than the conventional systems (Benatti et al. 1977). In Nigeria, Lal (1976a) reported negligible soil losses from no-till culture of soybeans, and attributed this to improved soil water storage and infiltration.

Contour Tillage and Ridging. Performing tillage operations and planting crops on the contour (across slope) rather than up and down slope often results in reduced soil loss. The practice was proven most useful on slopes of 3-7 percent in the United States (Wischmeier and Smith 1965, 1978). An effective variation of this method is contour ridging (listing) in which ridges and furrows are formed by listers (ridgers) and then maize, for example, is planted in the furrows. Another modification is contour strip-cropping, a practice in which strips of sod are alternated with strips of row crops or small grain planted on the contour (Wischmeier and Smith 1965, 1978). This is also more effective than contouring alone. Two cautions should be noted: In the absence of drainage provisions, if rainfall exceeds the retention or acceptance capacity of the soil, breakover of ridges may occur, and subsequent scouring may create greater erosion damage than that incurred from up-and-down-slope tillage and planting practices. Likewise, establishment of grass strips as little as 5 percent off the contour can result in very high soil losses. In the extreme, a fivefold acceleration of soil loss was observed from parallel-to-slope ridges when compared with non-ridged land in Africa (Kowal 1970). In summary, contouring and ridging should be used only on gentle slopes, should provide for drainage of excessive overland flow, and, when applied as the sole conservation measure, the contour rows should be laid out with precision and deliberately maintained to avoid breakover. Correctly done, contour strip-cropping and contour ridging are more effective than contouring alone.

Several other agronomic methods are used on gently sloping land. One is basin listing or tied ridging (Constantinesco 1976), a technique that establishes a large number of small basins in a cultivated field by creating numerous small dams in the furrows with a tying mechanism or shovel. Water ponded within the basins will ultimately percolate into the soil provided the soil is permeable. Contour bunding is another practice similar to tied ridging in that it is intended to be both soil conserving and water conserving. Used mostly in India, bunds are wide channels of level to low gradient, with the ends turned upward (Hudson 1975). However, Krantz et al. (1978) criticized the use of bunds as being ineffective for erosion and runoff control in the semiarid tropics. Considerable water and sediment movement can take place between consecutive bunds resulting in irregular crop performance for various locations in the field. Also the bunds are susceptible to frequent breakover as excess water concentrates at the lower end of the field. This causes more serious erosion than in the absence of bunds.

The mechanical control practices discussed so far are useful only on gentle slopes. However, with increasing population pressures in developing countries (see chap. 2), farms established on slopes of 20°-25° (36-47%) or more are not uncommon. To our knowledge, the extreme is found in Guatemala where the native Indians have been forced to farm lands with slopes as steep as 65° (214%) (Nadel 1976). Under such conditions it is imperative to reduce runoff volume and velocity by decreasing the length of slope and reducing the gradient in portions of the slope.

Terracing

Soil conservation terraces are artificial earth embankments constructed across slope at regular vertical intervals down the slope. They cut sloping land into narrow steps or platforms that effectively reduce the slope length and gradient within the cultivated portion (Constantinesco 1976). Runoff that collects on the terraces may be conserved (e.g. in semiarid regions) or disposed of through drainage into artificial waterways. Following the classification of Sheng (1977*a*), six major types of terraces will be described (Fig. 34).

Bench Terraces. Bench terraces are level or slightly sloping steps or platforms that run across the slope. The steps are supported by steep risers of earth protected by grass, or the risers may be constructed of rock walls. The terraces may be level, outward sloped, or inward sloped, the latter being preferred for the higher rainfall areas of the humid tropics. Level benches provided with enclosing dikes are particularly suited to paddy culture, while outward sloped benches are appropriate to semiarid regions with low rainfall intensity.

Sheng (Sheng and Stennett 1975) believes that bench terracing is particularly suitable for countries having steep slopes, dense populations, food shortages, high unemployment, and high rainfall intensity causing severe erosion. At Dehra Dun, India, Patnaik (1975) illustrated the efficacy of bench terracing over contouring on steeper slopes (25% in this case). Potatoes planted on the contour lost 15 Tm of soil/ha; soil losses were reduced to 1 Tm/ha on 3 m wide bench terraces with a 2.5 percent inward slope. Both sites received 1295 mm of rain. Engineering specifications are covered by Sheng (Sheng and Stennett 1975) and construction of terraces requires design and maintenance; they are not merely randomly placed steps on hillsides. A maximum slope of 30° (58%) is the practical limit for

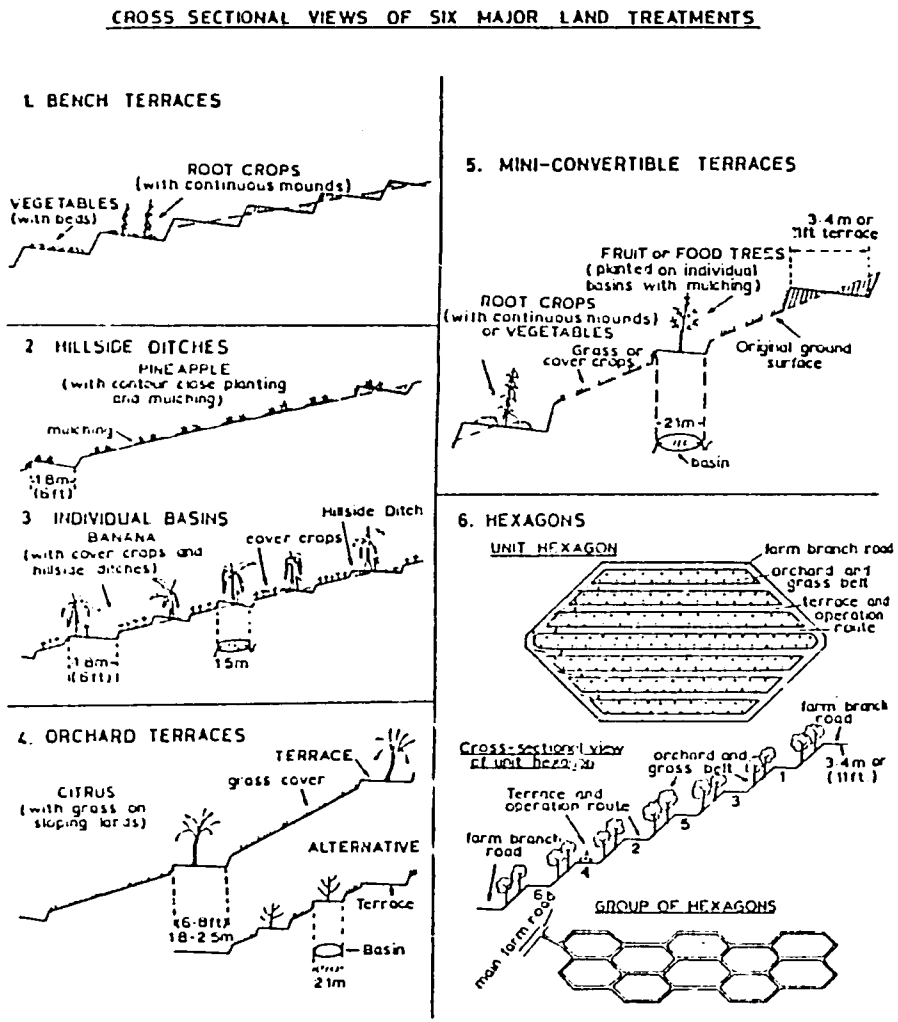


Figure 34. Major types of terraces. (Sheng 1977a)

bench terracing for cultivation; in Jamaica it is 25°. Limits are also placed on the length of the benches (100 m in Jamaica for example; Sheng and Stennett 1975); otherwise the velocity of runoff will be too great. Bench widths vary from 2.4 to 5.2 m for handmade benches and 3.4 to 6.4 m for those made with machinery.

Hillside Ditches. Hillside ditches are used to break a long slope into a number of short slopes so that runoff will be safely drained without causing erosion (Sheng and Stennett 1975). The most useful ditch is essentially a narrow reverse sloped bench. Only interspaces between ditches are cropped, so that contouring, mulching, or some other conservation treatment must be applied to prevent soil loss to the ditches. In both Taiwan and Jamaica, pineapples are successfully raised with this cultural system.

Individual Basins. Small round benches of approximately 1.5 m diameter are constructed for individual plants such as bananas or citrus. By themselves these basins are not enough to control erosion and hillside ditches are also installed, with cover crops between the basins and ditches. Individual basins of this sort have been used as well for direct seeding of forest tree species on steep slopes. This is an important conservation technique where land is dissected, where soil depth varies from deep to shallow, or where rocks and stones are present in large quantity (Sheng and Stennett 1975).

Orchard Terraces. These are essentially bench terraces constructed for fruit or food trees on steep slopes (25° to 30°). An inclination distance of 6.1 m is recommended for most orchard terraces and the space between the benches should be kept in permanent grass (Sheng and Stennett 1975).

Miniconvertible Terraces. Miniconvertible terraces have 3.4 m wide bench terraces interspersed with 1.5 to 2.1 m basins. Fruit or food trees are grown in the basins and vegetables or yams on the terraces, with grass or cover crops in between. This conservation practice provides greater flexibility than the other terrace procedures. If more intensive agriculture is desired, the slope can be converted solely to bench terraces. If less intensive agriculture is desired, then all the terraces can be planted to fruit or food trees (Sheng and Stennett 1975).

Hexagons. The "hexagon" method, designed for large or medium sized commercial orchards on sloping land, originated in Japan. As noted in Figure 33 the hexagon is formed by a farm branch road that encloses the orchard. Operation routes of four-wheeled tractors meet the farm branch road at an obtuse angle.

In order to design terraces in the field, many farmers and conservationists in the United States and elsewhere use a terrace-spacing formula (SCS 1975a) unless local conditions dictate other dimensions (Fig. 35). The formula for vertical spacing is:

$$VI = XS + Y \qquad (13)$$

where VI = vertical interval in feet; X = a variable from 0.4 to 0.8 that is dependent on rainfall intensity. (The Gulf States in the United States are assigned a value of 0.4, while drier states of the north central region, Northwest, and West have a value of 0.8); S = land slope in ft/100 ft; Y = a variable from 1.0 to 4.0. (Soils with below average water intake rates and cropping systems providing little cover have a value of 1.0, while 4.0 is assigned where tillage systems leave considerable cover).

For maximum horizontal interval the formula is:

$$HI = (XS + Y)\left(\frac{100}{S}\right) \qquad (14)$$

where HI = horizontal interval in feet; and the remaining terms are defined as before. It is important to note that both formulas 13 and 14 require site-specific values that are often not verified before use, with subsequent over- or under-designing of terraces.

The universal soil loss equation lends itself to

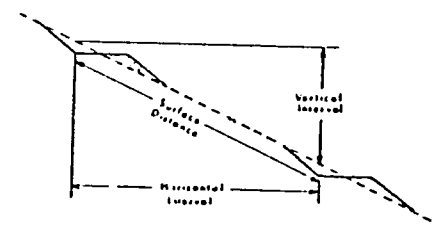


Figure 35. Horizontal and vertical interval measurements for spacing terraces. (Beasley 1972)

evaluating the horizontal interval of a terrace if the L and S factors are available.

$$HI = \left[\frac{100\,SL}{0.76 + 0.53s + 0.076s^2}\right]^2 \qquad (15)$$

where s = land slope in percent, and SL = E/KRCP, where E = allowable soil loss in tons/acre/yr, and K, R, C, and P are defined as in chapter 4.

However, this formula is not widely used outside the United States because quantitative values for the factors of the equation are not generally available. A report of a recent application in east Africa was provided by Hurni (1981).

Waterways

Although the various contouring and terracing techniques already described are used to reduce the velocity of flow and thus the scouring effect of runoff, excess water must be disposed of in definite channels, or artificially constructed waterways (Fig. 36). Specifications and design criteria are provided in the Engineering Field Manual (SCS 1975*a*), Hudson (1975), Beasley (1972), and other agricultural engineering books. Waterways take many different forms, some of which are explained below.

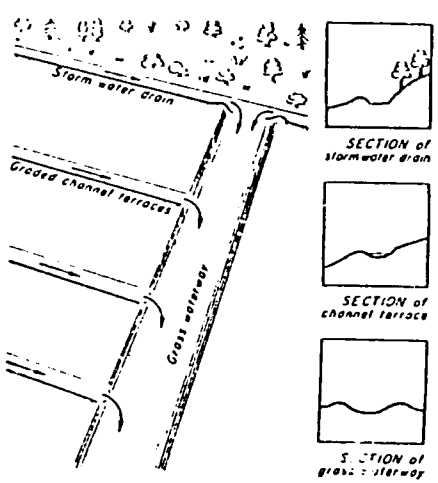


Figure 36. Major kinds of waterways. (Hudson 1971)

Diversions. A diversion is an individually designed graded channel with supporting ridge on the lower side, and is constructed across slope (SCS 1975*a*). Variously called storm water drains, diversion ditches, or diversion terraces (Hudson 1971), they are the first line of defense for protection of the cultivated area where there is danger from extraneous runoff from pastures or timberland above the cultivated land (Constantinesco 1976).

The major uses for diversions are to reroute water around gully heads, to protect lower terraces by diverting water from the upper terraces, to break up water concentrations on long gentle slopes, to reduce the length of slopes in conjunction with other conservation measures, to collect water for water harvesting systems, and so on. Cross sections of diversions may be either parabolic, trapezoidal, or V-shaped. The success or failure of a properly designed or constructed diversion is dependent on the outlet and on proper maintenance. Repair of damaged grassy areas in the sod and elimination of weeds are essential.

Channel Terraces. These channels are located across the slope so as to further interrupt the flow of water across the cropland. According to Hudson (1971) they are termed ridges or bunds in Commonwealth countries. They may be slightly graded or, in semiarid areas, built perfectly on the contour to absorb available water. Generally their shape is trapezoidal or V-shaped in cross-section. For most soils, water flow velocity in the channel should not exceed 0.61 m/sec if the channel is cultivated; 1.1 m/sec if not cultivated (Beasley 1972). Broad-based terraces (broad-based contour ridges) up to 15 m wide, in which row crops can be grown, are found in Zimbabwe and South Africa. The narrow-based contour ridges with steep-sided banks are up to 4 m wide and cannot be crossed by tractors; they are often used on tobacco fields in Africa (Hudson 1971).

Grassed Waterways. Grassed waterways are constructed waterways shaped to desired dimensions and vegetated for safe disposal of runoff from a field, diversion, terrace, or other structure (SCS 1975*a*). When used as an outlet for terraces they are often called "terrace outlets" (Beasley 1972).

Grassed waterways should be constructed in advance of other channels that discharge into them. Three shapes (parabolic, trapezoidal, V-shaped) are used but the parabolic cross-section is most satisfactory. The location of the grassed waterway should conform to the flow pattern of the area and ideally may be located in a naturally vegetated draw. Oftentimes gullies may be shaped into grassed waterways with bulldozer work followed by the planting of grass. Generally the flow velocity in the channel will vary from 0.91 to 2.13 m/sec depending on the soil type and vegetation present. In India it has been recommended (Shankarnarayan and Magoon 1974) that *Cynodon plectostachyus, Urochloa mosambicensis, Dichanthium annulatum,* and *Cynodon dactylon* may be used in waterways. Further to the north in Nepal it was found that thin Napier grass *(Pennisetum polystachyon)* had a greater basal area coverage, had a higher yield, and retained more silt than two other grasses tested for waterway stabilization (Sachdeve et al. 1976).

The selection of grasses for planting in waterways must be made with view of their adaptability to prevailing soils and the region's environmental conditions. Maintenance requires that damage to the sod be repaired quickly and a dense grass sward must be maintained by occasional fertilization if necessary. The waterway definitely should not be used as a footpath for animals or humans and care must be taken to prevent damage to the sod when moving machinery across it (Constantinesco 1976).

Structures

The installation of mechanical structures for erosion control should be considered a last resort. They are difficult and often expensive to construct and demand expertise in design. As pointed out by Hudson (1975) "Everything is against their being successful. They will be built in adverse conditions, in poor unstable soils, in remote inaccessible areas where maintenance will be poor, and then they will be expected to withstand the onslaught of torrential floods and to last forever." However, where vegetative measures alone or in combination with the land-shaping methods already described will not handle the water concentrations involved, structures may be used if economical. A structure is defined as a designed device, constructed or manufactured, that is used in soil and water conservation to retain, regulate, or control water flow (SCS 1975*a*). They are used specifically for grade and gully control, water storage, water retention (flood prevention), sediment storage, surface-water inlets, water-level control, irrigation, drainage, and shoreline and streambank protection.

The Soil Conservation Service (1975*a*) states that many structures are composed of the following components:

- an earth embankment that directs water through the spillway;
- a spillway inlet that is a box, a weir (dam) in a wall, or a culvert;
- a spillway conduit that is an enclosed box, pipe, or open channel;
- and a spillway outlet that is an apron with or without an energy dissipator or a cantilevered outlet.

Earth Embankments. These are used for ponds, irrigation reservoirs, and grade stabilization structures. As the basis for a silt-trap dam, such embankments have widespread use to reduce the sediment load of downstream water supplies. For example, urban development often requires an embankment during construction, for collecting sediment from the site.

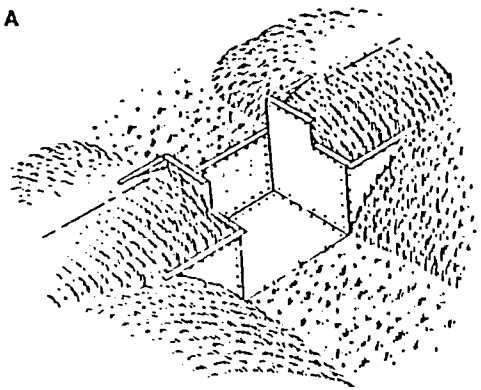
Obviously preliminary survey work is needed to build a functional embankment. The nature of the soil as well as certain geological data need be gathered if an impounding structure is desired. (For example, soils composed largely of shrink-swell clays might be unsuitable.) The presence of pockets of permeable materials, an extreme case being lava tubes in Hawaii, is necessary preconstruction information.

Spillway inlets, conduits, and outlets. Water impounded by an embankment enters the spillway through a box, a weir in a wall, or a culvert-type entrance. In certain structures a conduit (pipe or rectangular channel) carries water through the structure. At the outlet, safe disposal of water is necessary and is accomplished by a stilling basin (the apron of the structure) or strategically placed blocks which serve as energy dissipators.

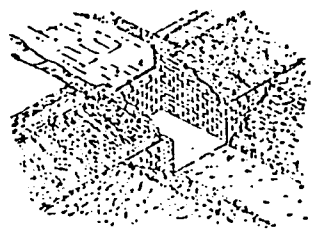
Figure 37 illustrates several forms of concrete or metal structures that may be used; however a great number of designs have been employed. Obviously none of the foregoing structures should be installed without consulting a knowledgeable engineer. Figure 38 gives a general rule-of-thumb chart to determine the required spillway type.

Various natural or synthetic materials are used to construct check dams that slow the course of water in a gully. A rock-fill dam (Fig. 39) anchored by wire netting is one possibility. Another is the use of wire netting secured by posts. Brush or straw is

A



Prefabricated metal



Concrete block

B

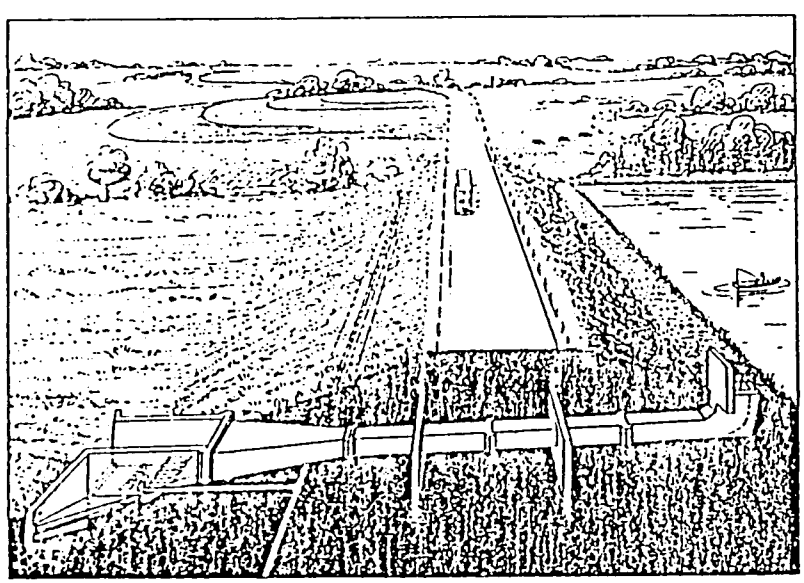
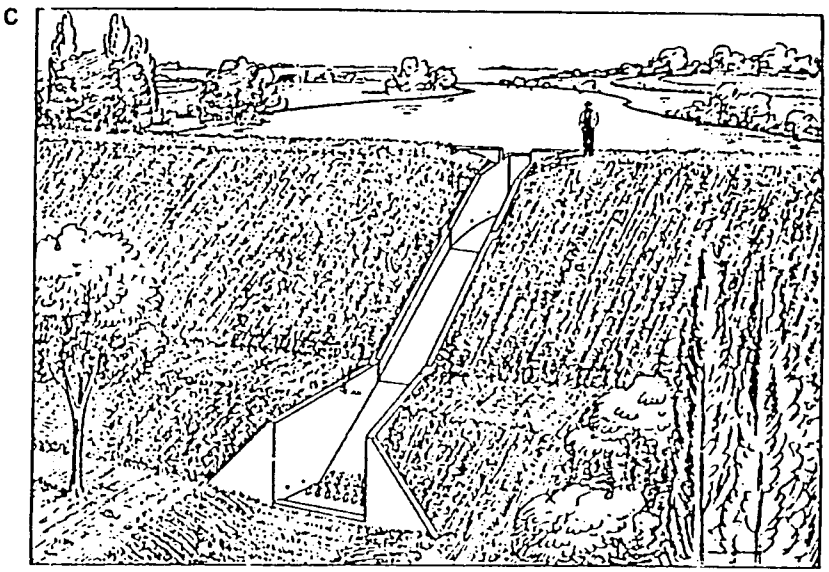


Figure 37. Various kinds of spillways: *A*. Two drop spillways; *B*. A monolithic drop inlet spillway; *C*. A chute spillway. (SCS 1973a)

C



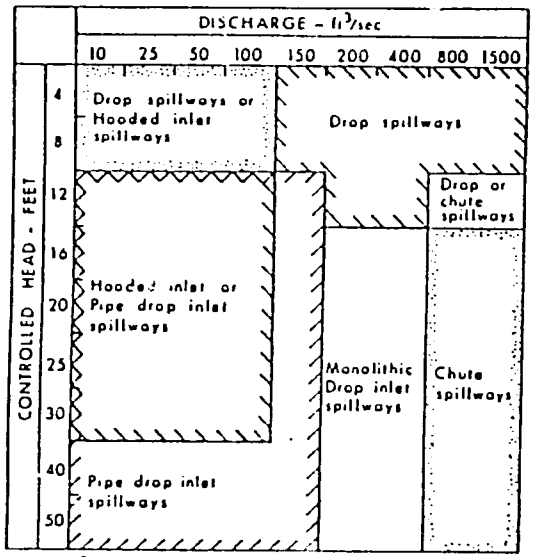
placed on the upstream side of the netting, which slows runoff and builds up sediment upstream of the dam. Brushwood dams (Fig. 40*a*) in which branches are tightly packed together horizontally and secured across the gully by vertical stakes or by tying with wire, are also utilized. A more substantial structure may be constructed with two rows of vertical posts driven into the channel floor and logs packed in between (Fig. 40*b*). If there is considerable flow the dam should have a rectangular notch, which must be wide enough to pass the full flood of water, without restriction, otherwise scouring of the banks will take place. Finally, used or discarded bricks may be used to build a weir. Since such a structure lacks "weep holes," it lacks tensile strength and should be buttressed. More complete discussions of these temporary structures may be found in Hudson (1971) and Weidelt (1975).

Gully Control and Stabilizing Slopes

Hudson (1971) said "In gully control a bag of fertilizer is more effective than a bag of cement." However, it is not always possible to check downcutting and head cutting, the main subprocesses of gully formation, by vegetative measures alone. Tentatively, we accept the classification of Sheng and Stennett (1975) that small gullies are less than 0.9 m deep, medium gullies are 0.9 to 4.6 m deep, and large gullies are over 4.6 m deep. The simple procedure of fencing the gully from cattle, followed by revegetation, may be effective on small and perhaps medium gullies (Constantinesco 1976). Normally, more effort is required for larger gullies.

Generally a diversion (storm-water drain) around the head of the gully is a first step to control runoff (Bennett 1939; Constantinesco 1976). The diversion normally is located above the gully head at a distance of 3 to 4 times the depth of the gully. A safe grade in the diversion is 0.45 to 0.90 m per 100 m (USDA 1973). A general rule of thumb in India is that a gully with a waterway slope up to 19 percent and a small drainage area can be controlled by leveling the slopes and vegetating the gully (Singh 1974).

Although the final objective is revegetation of any gully, mechanical structures may be mandatory for stabilizing head cuts of large gullies and ravines (Heede 1977). In the Philippines these may be brush cover, riprap interplanted with cuttings, pole structures, solid structures of gabions, or occasionally grass sods (Weidelt 1975). Although temporary



Note: Chart shows most economical structure as related to discharge and controlled head providing site conditions are adequate.

Figure 38. Guide to structure selection. (SCS 1975a)

Figure 39. A rock-fill check dam. (Heede 1977)

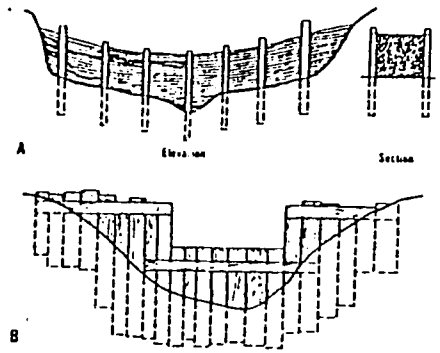


Figure 40. Temporary dam structures: A. Brushwood dam; B Timber and log dam. (Hudson 1975)

structures are not recommended in the United States (USDA 1973), in the labor intensive societies of many developing countries such structures seem quite justified. Most favored plants for gully control are those of great density, low height, with sufficiently strong vegetative portions to remain erect under intense rainfall impact or overland flow, and with deep dense root systems (Heede 1977). Tall grasses are not generally recommended for gully stabilization as they lie flat under flow impact and may substantially increase flow velocities.

It has been concluded that afforestation alone will not reclaim gullies in western and central India. The problem must be solved on the individual watersheds where peripheral bunds and drop structures at gully heads can arrest gully progress. In the eastern red soil region of India earthen check dams are being used. Paddy benches are developed below the storage dams (Das 1977). Only porous check dams (those with "weep holes") are recommended for wild lands and elsewhere in the United States, as they require less anchoring than the nonporous types. Oftentimes loose-rock check dams (Fig. 39) can be constructed from available rock in the area, using rock alone or with wire mesh, gabions, fencing, and so on (Heede 1977).

Use of flexible stone-filled bolsters has been recommended for trapping silt and reclaiming gullies in Zimbabwe (Stocking 1976). Intensive methods of correcting existing tunnels in Australia involve mechanical and vegetative methods. Initially, contour plowing or ripping is employed, with the threefold purpose of breaking up crusts, aiding water infiltration, and preventing surface water accumulations. True control is then accomplished by revegetating the problem site and proper management thereafter (Stocking 1976).

Grassed waterways may be constructed from existing gullies if the necessary machinery is available. Small and medium-sized gullies may be reshaped with a bulldozer. The channel cross-section should be broad and flat and, after the proper form is achieved, should be seeded with native grasses. Usually the soil in the bed of a reworked gully is poor so that oftentimes sacks (jute, paper, etc.) of good soil are laid in shallow trenches in the floor of the channel. Then the bags are slit and the grass seedlings are planted through the slit. This reduces chances for washing away the soil and seedlings before the grass is established (Hudson 1975). The depth of flow should be 0.15 to 0.45 m to keep the flow velocity between 0.91 and 1.82 m/second. The gradient should not exceed 10 percent (10 m drop/100 m length). Ponds may be located at the ends of the grassed waterways that serve as water-storage areas for livestock, fish farming, or recreation (USDA 1973).

As one example in the tropics, the general principles as stated above have been used to renovate the spectacular *laraka*s in various places on Madagascar. Diversion ditches were provided above the *laraka* head and the slopes of the walls were reduced to prevent collapse. This was followed by installing log fascines, stone gabions, or holding plant dikes in position with wire netting; revegetating with grasses, such as elephant grass, bushes (*Mimosa*) or trees (*Eucalyptus* spp.), and raising the base level by means of dikes across the outlet (Le Bourdiec 1972).

Control in Lumbering and Land Clearing

Logging operations may cause major erosional problems, especially in the humid tropics where there is accelerated lumbering activity and the rainfall is particularly aggressive. Tree felling itself causes only minor erosional disturbance. Tractor skid trails (snig tracks) and logging roads are most vulnerable to erosion. Studies in northern Queensland indicate that in group selection tractor logging in a rainforest, 18-21 percent of the area is covered with skid trails, of which 70 percent are bare soil (Gilmour 1977). To keep soil loss to a minimum Gilmour proposed the following guidelines:

1. Keep all roads, skid trails, and log ramps as far from streams as possible.

2. Use a logging arch in tractor skidding rather than dragging the logs.
3. Keep the grades for roads and trails as low as possible.
4. Ensure adequate drainage of roads and trails.
5. Practice uphill logging wherever possible.
6. Upon completion of logging, before the rainy season, inspect potential problem areas on roads, and seed or hydromulch where necessary.

Valuable suggestions made by Megahan (1977) for forest road construction in the United States are also applicable to the tropics. Such obvious but frequently ignored suggestions as keeping logging roads as narrow as possible, locating roads away from high erosion hazard sites, and taking advantage of ridge tops, natural benches, and lower gradients for locating roads exemplify the recommendations Megahan made.

A number of suggestions made for land clearing in Surinam (Van der Weert 1974) should apply quite generally throughout the tropics. For example there is generally an inverse logarithmic relationship between the force necessary for compaction and soil water content. Since compaction reduces infiltration of water, all clearing and windrowing should be done during the dry season, and burning should precede windrowing. To keep the number of passages of vehicles as low as possible, distances between windrows should be twice the future plant interrow distance rather than the 40 to 50 meter spacing normally used. Van der Weert suggested that a bulldozer with a K. C. Stinger blade for cutting down trees should be used rather than a bulldozer alone, as the latter causes considerable soil disturbance when uprooting the trees. Finally, stump clearing should be carried out only when stumps greatly impede access to the area.

Row planting of teak in Trinidad (Bell 1973) has caused serious soil losses. Control measures recommended are group planting of teak with shrub growth established between groups; use of unplanted strips by gardeners for one year followed by establishment of shrub growth; and control of burning. Bell even went so far as to suggest elimination of teak altogether as a wood crop in Trinidad if all else fails.

Erosion control on tea estates in Sri Lanka (Lester-Smith 1938) was advocated as a combination of mechanical and vegetative procedures. Hedges of sword plant *(Sansevieria guineensis)* and Ceylon bowstring hemp *(S. Zeylanica)* were recommended for planting on contour as sediment traps. Carpet grass *(Axonopus compressus)*, Australian daisy *(Erigeron mucronatum)* and *Indigofera endecaphylla* were advocated for bank stabilization.

Another problem of irregular occurrence in association with logging or clearing is landslides or mass wasting. This is the dominant form of soil loss on steep-sloped watersheds where shallow slides (debris avalanches) are most likely to be initiated by logging or destruction of forest cover. Roads cause slides more frequently than the actual timber harvest although clearcutting reduces slope strength more than any other logging system. Clearcutting is not recommended in steep terrain (Hattinger 1976, Rice 1977). Similarly the effect of fires on slopes in the long term is to increase the risk of slides (Rice 1977).

Torrent flow is another feature of forests that can cause severe problems, especially to forest roads. Roads built parallel to the channel of a torrent, or a road cutting across such a channel, may be severely damaged. In the first instance bank erosion is the main threat to the road; in the second, the culvert, bridge, or paved ford may be damaged, especially if debris blockage occurs (Hattinger 1976). Protection of channel banks is recommended by riprap (rocks), sills and check dams for channel-bed and bank protection; groynes to divert flowing water; and line ditches, check dams, and the like for flood discharge. To protect bridges, culverts, or fords against bed erosion and against blocking, sills and check dams are used (Hattinger 1976).

For stabilizing slopes and road cuts in developing countries, retaining walls of riprap (rocks) are commonly used. Interplanting of the riprap with vegetation may be employed as well (Weidelt 1975). Where stronger structures are needed, gabions are used at the bottom of a slope; these are prefabricated, heavy, galvanized wire baskets filled with rocks. Weidelt (1975) stresses that the first line of gabions should always be inclined toward the slope. An ingenious, and at the same time economical, use can be made of worn-out automobile tires to construct retaining walls or to place them flat on the slopes (Fig. 41). Where possible, vegetation is interplanted in the inner circle of soil defined by the tire (Weidelt 1975).

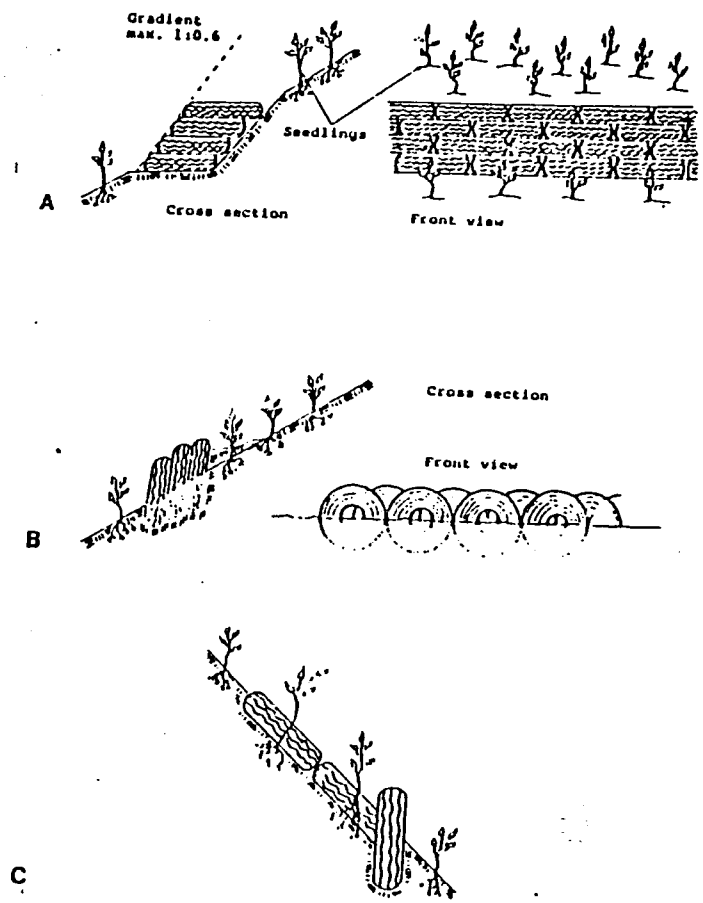


Figure 41. Use of worn tires for stabilizing slopes: *A.* Retaining wall; *B.* Low barrier; *C.* Cover. (Weidelt 1975)

El-Swaify, S.A., E.W. Dangler and C.L. Armstrong. 1979. Literature cited. In Soil erosion by water in the tropics: A state of the art. Washington, D.C.: United States Agency for International Development.

LITERATURE CITED

Adu, S. V.
1972 Eroded savanna soils of the Navrongo-Bawku area, northern Ghana. Ghana Jour. of Agric. 5:3-12.

Ahmad, E.
1973 Soil erosion in India. New York: Asia Publ. House.

Ahmad, N.
1977 Erosion hazard and farming systems in the Caribbean countries. *In* Greenland and Lal 1977, pp. 241-249.

Ahmad, N., and E. Breckner
1974 Soil erosion on three Tobago soils. Trop. Agric. (Trinidad) 51(2):313-324.

Ahn, P. M.
1977 Erosion hazard and farming systems in East Africa. *In* Greenland and Lal 1977, pp. 165-176.

Aina, P. O., R. Lal, and G. S. Taylor
1977 Soil and crop management in relation to soil erosion in the rainforest of western Nigeria. *In* SCSA 1977, pp. 75-82.

Allan, W.
1965 The African Husbandman. New York: Barnes and Noble.

Alleyne, E. P. and M. J. Percy
1966 Runoff and soil loss on two small watersheds in the northern range, Trinidad. Trop. Agric. (Trinidad) 43(4):323-326.

Anderson, H. W.
1975 Sedimentation and turbidity hazards in wildlands. *In* Watershed Management, pp. 347-376. Proc. Amer. Soc. Civil Engineers, Watershed Management Symp., Div. Irrig. and Drainage. Logan, UT.

Andrade, A., and V. Payan
1973 El pais en riesgo de convertirse en un paramo. Mex. For. 47(5):31-32.

Armstrong, C. L., E. W. Dangler, and S. A. El-Swaify
n.d. Soil erosion by water in Africa: A bibliography. Honolulu: CTAHR. In preparation.

Armstrong, C. L., J. K. Mitchell, and P. N. Walker
1980 Soil loss estimation research in Africa: A Review. *In* DeBoodt and Gabriels 1980, pp. 285-294.

Arnoldus, H. M. J
1974 Soil Erosion: A review of processes, assessment techniques. Expert Consultation on Soil Degradation. Rome: FAO/UNEP.
1977*a* Methodology used to determine the maximum potential average annual soil loss due to sheet and rill erosion in Morocco. *In* FAO 1977*c*, pp. 8-9.
1977*b* Predicting soil losses due to sheet and rill erosion. *In* FAO 1977*a*, pp. 99-124
1980 An approximation of the rainfall factor in the universal soil loss equation. *In* DeBoodt and Gabriels 1980, pp. 127-132.

ARS (Agricultural Research Service, USDA)
1975*a* Control of water pollution from cropland, vol. 1: A manual for guideline development. USDA-ARS-H-5-1. Washington, DC: Govt. Printer.
1975*b* Present and prospective technology for predicting sediment yields and sources. USDA-ARS-S-40. Washington, DC: Govt. Printer.

Ateshian, J. K.
1974 Estimation of rainfall erosion index Jour. of Irrigation and Drainage Division of Amer. Soc. Civil Eng. 100 (IR3):293-307.

Atkinson, G. D.
1971 Forecasters' guide to tropical meteorology. Tech. Rep. no. 240, U.S. Air Force, Air Weather Service (MAC). 1 April.

Bagley, G. R.
1973 Conservation tillage doesn't cost—it will pay. *In* SCSA 1973, pp. 1-4.

Baillie, I. C.
1975 Piping as an erosion process in the uplands of Sarawak. Jour. of Trop. Geog. 41:9-15.

Bailly, C., C. Malvos, J. Sarrailh, J. Rakotomanana, L. Rampanana, and M. Ramanahadray
1976 Etude de la sensibilité des sols de Madagascar à l'érosion. Bois et Forets des Tropiques 169:15-28.

Balek, J.
1977 Hydrology and water resources in tropical Africa. Amsterdam: Elsevier Scientific Publ. Co.

Barber, R. G., D. B. Thomas, and T. R. Moore
1981 Studies on soil erosion and runoff and proposed design procedures for terraces in the cultivated semi-arid areas of Machakos District, Kenya. *In* ICSC 1981, pp. 219-238.

Barker, G. H.
1968 Soil and land-use surveys no. 24: Jamaica, Parish of St. Ann. Univ. of West Indies, Trinidad.
1970 Soil and land-use surveys no. 25: Jamaica, Parish of Trelawney. Univ. of West Indies, Trinidad.

Barnes, D. L. and M. J. Franklin
1970 Runoff and soil loss on sandveld in Rhodesia. Grassl. Soc. S. Afr. Proc. 5:140-144.

Barnett, A. P., J. R. Carreker, F. Abruna, and A. E. Dooley
1971 Erodibility of selected tropical soils. Trans. Amer. Soc. Agric. Engin. 14(3):496-499.

Barnett, A. P., J. R. Carreker, F. Abruna, W. A. Jackson, A. E. Dooley, and J. H. Holladay
1972 Soil and treatment losses in runoff with selected cropping treatments on tropical soils. Agron. Jour. 64(3):391-395.

Bartram, P.
1975 A performance standard for erosion control. Technical Rep. no. 3. Honolulu: Hawaiian Environmental Simulation Laboratory (HESL), University of Hawaii.

Bates, J. A. R.
1960 Studies on a Nigerian forest soil: I. The distribution of organic matter in the profile and in various soil fractions. Jour. Soil Sci. 11(2):246-256.

Baumgardner, M. F., R. A. Weismiller, and F. R. Kirschner
1978 Digital analysis of landsat data for soil survey and erosion assessment. Presented at the Workshop on Assessment of Soil Erosion in the U.S.A. and Europe (Ghent, 1978).

Baver, L. D.
1968 The effect of organic matter on soil structure. Pontificiae Academiae Scientiarum Scripta Varia 32:383-413.

Beasley, R. P.
1972 Erosion and sediment pollution control. Ames, IA: Iowa State Univ. Press

Bell, T. I. W.
1973 Erosion in the Trinidad teak plantations. Commonwealth Forest. Rev. 52(3):223-233.

Benatti, R., Jr., J. Bertoni, and C. A. Moreira
1977 Perdas por erosao emplantio directo e convencional de milho em dois solos de Sao Paulo. Revista Brasileira de Ciencia do Solo 1:121-123

Bennema, J. and T. De Meester
1981 The role of soil erosion and land degradation in the process of land evaluation. *In* ICSC 1981, pp. 77-86

Bennett, H. H.
1939 Soil conservation. New York: McGraw-Hill

Bhatia, K. S., and R. S. Singh
1976 Evaluation of rainfall intensities and erosion index values for soil conservation. Indian For. 102(10):726-734.

Bishan, Mansingh
1957 Erosion and its control. Jour. Indian Soil Sci. Soc. 5:229-233.

Blair, T. A., and R. C. Fite
1965 Weather elements. Englewood Cliffs, NJ: Prentice Hall.

Blair-Rains, A. R.
1981 Erosion risk assessment and land classification for conservation design. *In* ICSC 1981, pp. 57-61.

49

Blanchard, D. C.
1950 Behavior of water drops at terminal velocity. Trans. Amer. Geophysical Un. 31:836-842.
1953 Raindrop size-distribution in Hawaiian rains. Jour. of Meteorology 10:457-473.
Blandford, D. C.
1981 Rangelands and soil erosion research: A question of scale. *In* ICSC 1981, pp. 105-121.
Bleeker, P.
1975 Explanatory notes to the land limitation and agricultural land use potential map of Papua New Guinea. Land Research Ser. no. 36. Melbourne: CSIRO.
Bols, P. L.
1978 The iso-erodent map of Java and Madura. Rep. of the Belgian Technical Assistance Project ATA 105. Bogor, Indonesia: Soil Research Institute.
Bonnet, J. A., and M. A. Lugo Lopez
1950 Relative erosiveness of Puerto Rico soil. Journ. Agric. Univ. Puerto Rico 34:294-307.
Bonsu, M.
1981 Assessment of erosion under different cultural practices on a savanna soil in the northern region of Ghana. *In* ICSC 1981, pp. 247-253.
Boon, W., and J. Savat
1981 A nomogram for the prediction of rill erosion. *In* ICSC 1981, pp. 303-320.
Bork, H. R., and H. Rohdenburg
1981 Rainfall simulation in southeast Spain: Analysis of overland flow and infiltration. *In* ICSC 1981, pp. 293-302.
Brooks, F. L.
1977 Use of the universal soil loss equation in Hawaii. *In* SCSA 1977, pp. 22-30.
Brown, L. H.
1971 The biology of pastoral man as a factor in conservation. Biol. Conserv. 3(2):93-100.
Brown, L. R.
1978 The worldwide loss of cropland. Worldwatch Paper no. 24. Washington, DC: Worldwatch Institute.
Brunig, E. F.
1970 On the ecological significance of drought in the equatorial wet evergreen (rain) forest of Sarawak (Borneo). Sympos. on Water Relations in Malaysian Forests, Aberdeen-Hull Sympos. on Malaysian Ecology 1, pp. 66-68.
Budowski, G.
1956 Tropical savannas, a sequence of forest felling and repeated burning. Turrialba 6(1-2):23-33.
Bunting, B., and J. N. Milsum
1928 Cover crops and green manures. Malaysian Agric. 16:256-280.
Buol, S. W., F. D. Hole, and R. J. McCracken
1973 Soil genesis and classification. Ames, IA: Iowa State University Press.
Bureau of Soils and PCARR (Philippine Council for Agriculture Resources Research)
1977 The Philippines recommends for soil conservation 1977. Los Banos.
Burgess, P. F.
1971 The effect of logging on a hill dipterocarp forest. Malay Nat. Jour. 24(304):231-237.
Burns, R. V.
1947 Soil erosion in Ceylon with particular reference to floods. Trop. Agric. (Ceylon [Sri Lanka]) 103:240-245.
Carter, C. E., J. D. Greer, H. Braud, and J. Floyd
1974 Raindrop characteristics in South Central United States. Trans. ASAE 17(6):1033-1037.
Carter, L. J.
1977 Soil erosion: The problem persists despite the millions spent on it. Science 196:409-411.
Carter, V. G., and T. Dale
1974 Topsoil and civilization. Norman, OK: Univ. of Oklahoma Press.
Chambers, D. V.
1977 Mahaweli watershed management study —Sri Lanka. Consultant's Report, 30 October. Boreham Wood, England: Hunting Surveys and Consultants Ltd.
Charreau, C.
1968 Rain and erosion. Sols Africains 13:241-244.
1969 Influence des techniques culturales sur le developpement du ruissellement et de l'erosion en Casamance. Agron. Trop. (Paris) 24:836-844.
Chase, J. L. H.
1976 A solution to Bolivia's greatest agricultural problem. Quarterly Rev. 2(4): 15-17.

Chen, Charn-Ning
1974 Effect of land development on soil erosion and sediment concentration in an urbanizing basin. IAHS-AISH Publ. no. 113:150-157.
Chim, L. T.
1974 A note on soil erosion study at Tawau Hills Forest Reserve. Malay. Nat. Jour. 27:20-26.
Chim, L. T., and S. P. Soon
1973 Land planning and conservation in Sabah. *In* Proc. Symp. Biol. Res. and Nat. Dev. (Agricultural aspects), pp. 45-47. Sandakan, Sabah: Forest Research Branch, Dept. of Agric.
Chisci, G.
1981 Empirical studies of soil erosion and conservation. *In* ICSC 1981, pp. 155-174.
Chisci, G., and C. Zanchi
1981 The influence of different tillage systems and different crops on soil losses on hilly silty-clayey soil. *In* ICSC 1981, pp. 211-217.
Chorley, R. J., ed.
1969 Water, earth, and man. London: Methuen.
Christ, J. H.
1960 Aloha Hawaii—some water and soil conservation aspects in the island paradise. Jour. of Soil and Water Conserv. 15:11-19.
Christiansson, C.
1972 Notes on morphology and soil erosion in Kondoa and Singida districts, central Tanzania. Geografiska Annaler 54A: 319-324.
Cochrane, G. R.
1967 Land use problems in the dry zone of Viti Levu. Proc. 5th New Zealand Geogr. Conf., pp. 111-118. Auckland: N.Z. Geogr. Soc.
Constantinesco, I.
1976 Soil conservation for developing countries. Soils Bull. no. 30. Rome: FAO.
Cook, H. L.
1936 The nature and controlling variable of the water erosion process. *In* Proc. Soil Sci. Soc. Amer. 1:487-494.
Cormery, Y., and J. Masson
1964 Etude de conservation des eaux et du sol au Centre de Reserches du Genie Rural de Tunisie. Application à un projet-type de la formule de perte de sols de Wischmeier. Cahiers ORSTOM Pédologie Tome 11, no. 3:?-26.
Council of Soil and Water Resources Research
1977 Effects of sediment deficit on various soil properties and fertilizer requirements. Sixth report. Cairo: Acad. for Scient. Res. and Tech. (In Arabic.)
Crouch, R. J.
1976 Field tunnel erosion: A review. Jour. Soil Conservation Service, New South Wales, 32(2):98-111.
1978 Variation in the structural stability of soil in a tunnel-eroding area. *In* Modification of Soil Structure, eds. W. W. Emerson, R. Bond, and A. R. Dexter, pp. 267-274. Chichester. Wiley.
CSWCRTI (Central Soil and Water Conservation Research and Training Institute)
1977 Annual Report. ICAR. Dehra Dun, India.
Cumberbatch, E. R. St. J.
1969 Soil properties and the effect of organic mulches on reclamation of Scotland clays, Barbados. Trop. Agric. (Trinidad) 46:17-24.
Dangler, E. W., and S. A. El-Swaify
1976 Erosion of selected Hawaii soils by simulated rainfall. Jour. Soil Sci. Soc. Amer. 40(5):769-773.
Dangler, E. W., S. A. El-Swaify, L. R. Ahuja, and A. P. Barnett
1976 Erodibility of selected Hawaii soils by rainfall simulation. ARS W-35.
Daniel, J. G., and A. Kulasingam
1974 Problems arising from large scale forest clearing for agricultural use—the Malaysian experience. Malaysian Forester 37(3):152-160.
Das, D. C.
1977 Soil conservation practices and erosion control in India—a case study. *In* FAO 1977*b*, pp. 11-50.
de Boer, I. J.
1977 De relatie land bouw-natuur bescherming in Azie, II: Shifting cultivation in Noord-Thailand. Tijdschrift der koninklijke Nederlandsche Heidemaatschappij 88(3): 103-111.
DeBoodt, M.
1975 Use of soil conditioners around the world.

Spec. Publ. no. 7, pp. 1-12. Madison, WI: Soil Sci. Soc. of Amer.

DeBoodt, M., and D. Gabriels, eds.
1980 Assessment of erosion. Chichester: Wiley.

Delwaulle, J. C.
1973 Resultats de six ans d'observations sur l'érosion au Niger. Revue Bois et Forets 150:15-37.

De Ploey, J.
1981 Crusting and time-dependent rainwash mechanisms on loay soil. *In* ICSC 1981, pp. 139-152.

de Rosayro, R. A.
1947 Forests and erosion—with special reference to Ceylon. Trop. Agric. (Ceylon [Sri Lanka]) 103:246-252.

Dils, R. E.
1977 A reassessment of watershed conditions, problems, and research needs in Taiwan. Jour. Chinese Soil and Water Conserv. 6(1):43-58.

Diseker, E. G., and J. M. Sheridan
1971 Predicting sediment yields from roadbanks. Trans. Amer. Soc. Agric. Engin. 14(1):102-105.

Douglas, I.
1981 Erosion risk assessment and land classification for soil conservation. *In* ICSC 1981, pp. 63-73.

Douglas, T.
1967 Natural and man-made erosion in the humid tropics of Australia, Malaysia, and Singapore. Int. Assoc. Sci. Hydrol. 75:17-30.

Downes, R. G.
1963 Soil conservation—who is responsible in Australia. *In* Soil Conservation in the Pacific, conv. J. H. Christ, pp. 43-48. Honolulu: Univ. of Hawaii Press.

Duckett, J. E., and P. Tan
1974 *Alternanthera brasiliana*—a useful supplementary cover in oil palm plantings. Malaya Planter 50(557):120-124.

Dudal, R.
1981 An evaluation of conservation needs. *In* ICSC 1981, pp. 3-12.

Dunne, T.
1977*a* Evaluation of erosion conditions and trends. *In* FAO 1977*a*, pp. 53-83.
1977*b* Studying patterns of soil erosion in Kenya. *In* FAO 1977*b*, pp. 109-122.

Dunne, T., M. J. Brunengo, and W. E. Dietrich.
1978 Cenozoic erosion rates in Kenya estimated from erosion surfaces. Dept. of Geological Sciences and Quarternary Research Center, Univ. of Washington, Seattle, Unpubl.

Dunne, T., W. E. Dietrich, and M. J. Brunengo
1978 Recent and past erosion rates in semiarid Kenya. Zeitschrift fur G. .orphologie. Supplementband 29:130-.40.

Eckholm, E. P.
1976 Losing ground. New York: Norton.

Ekern, P. C.
1977 Turbidity and sediment-rating curves for streams on Oahu, Hawaii. *In* SCSA 1977, pp. 242-254.

Ellison, W. D.
1944 Studies on raindrop erosion. Agric. Eng. 25:131-136.
1947*a* Soil erosion studies, pt 1. Agric. Eng. 28:145-146.
1947*b* Soil erosion studies, pt 2. Soil detachment hazard by raindrop splash. Agric. Eng. 28:197-201.

Ellison, W. D., and O. T. Ellison
1947 Soil erosion studies, pt 7. Soil transportation by surface flow. Agric. Eng. 28(10): 442-444, 450.

El-Swaify, S. A.
1977 Susceptibilities of certain tropical soils to erosion by water. *In* Greenland and Lal 1977, pp. 71-77.
1981 Controlling erosion problems: Propelling our way out of the merry-go-round. *In* ICSC 1981, pp. 549-555.

El-Swaify, S. A., and K. R. Cooley
1980 Sediment losses from agricultural watersheds in Hawaii. Agricultural Reviews and Manuals no. 17. SEA-USDA-W Series. Oakland, CA: USDA.
1981 Soil losses from sugarcane and pineapple land in Hawaii. *In* DeBoodt and Gabriels 1980, pp. 322-340.

El-Swaify, S. A., and E. W. Dangler
1977 Erodibilities of selected tropical soils in relation to structural and hydrologic parameters. *In* SCSA 1977, pp. 105-114.

El-Swaify, S. A., and S. K. Lim
1977 Effective dispersion of tropical soils for particle size distribution analysis. Agronomy Abstracts. Madison, WI: ASA.

Eltz, F., N. Cogo, and J. Mielniczuk
1977 Perdas por erosao em diferentes manejos de solo e cobertures vegetais em solo lateritico Bruno avermelhado distrofico (Sao Jeronimo). I. Resultados do primeiro ano. Revista Brasileira de Ciencia do Solo 1:123-127.

Elwell, H. A.
1977 A soil loss estimation system for southern Africa. Res. Bull. no. 22. Causeway, Rhodesia [Zimbabwe]: Dept. of Conservation and Extension.
1981 A soil loss estimation technique for southern Africa. *In* ICSC 1981, pp. 281-292.

Elwell, H. A., and M. A. Stocking
1973*a* Rainfall parameters for soil loss estimation in a tropical climate. Jour. Agric. Engin. Res. 18:169-177.
1973*b* Rainfall parameters to predict surface runoff yields and soil losses from selected field-plot studies. Rhod. Jour. Agric. Res. 11:123-129.
1974 Rainfall parameters and a cover model to predict runoff and soil loss from sandveld grazing trials in Rhodesia. Proc. Grassland Soc. South Africa 9:157-163.
1975 Parameters for estimating annual runoff and soil loss from agricultural lands in Rhodesia. Water Resour. Res. 11(4): 601-605.
1976 Vegetal cover to estimate soil erosion hazard in Rhodesia. Geoderma 15: 61-70.

FAO (Food and Agriculture Organization)
1954*a* Soil erosion survey of Latin America, pt 1: Jour. of Soil and Water Conserv. 9:158-168.
1954*b* Soil erosion survey of Latin America, pt 2: South America. Jour. of Soil and Water Conserv. 9:214-229, 237.
1954*c* Soil erosion survey of Latin America, pt 3: Agents of soil erosion. Jour. of Soil and Water Conserv. 9:275-280.
1957 Shifting cultivation. Unasylva 11(1). Reprinted in Trop. Agric. (Trinidad) 34:159-164.
1965 Soil erosion by water: Some measures for its control on cultivated lands. Rome.
1971 Land degradation. Soils Bull. no. 13. Rome.
1977*a* Guidelines for watershed management. Conservation Guide no. 1. Rome.
1977*b* Soil conservation and management in developing countries. Soils Bull. no. 33. Rome.
1977*c* Assessing soil degradation. Soils Bull. no. 34. Rome.

Finch, T. F.
1961 Soil and land-use surveys no. 11: Jamaica, Parish of Portland. Univ. of West Indies, Trinidad.

Finch, T. F., and T. A. Jones
1959 Soil and land-use surveys no. 7: Jamaica, Parish of Clarendon. Univ. of West Indies, Trinidad.

Fitzgerald, K.
1975 Regional pasture development and associated problems, I: Northwestern Australia. Tropical Grassland 9(2): 77-88.

Floyd, B.
1965 Soil erosion and deterioration in eastern Nigeria. Nigerian Geog Jour. 8:33-44.

Foglino, F.
1965 Le lotta antierosiva in Ecuador. Introduzione della *Setaria splendida* Stapf. per la formazione dei ciglioni. Revista D'Agricultura Subtropicale e Tropicale 59:473-481.

Foster, G. R.
1981 Conservation practices in erosion models. *In* ICSC 1981, pp. 273-278.

Foster, G. R., L. D. Meyer, and C. A. Onstad
1977*a* An erosion equation derived from basic erosion principles. Trans. ASAE 20(4): 678-682.
1977*b* A runoff erosivity factor and variable slope length exponents for soil loss estimates. Trans. ASAE 20(4):683-687.

Foster, G. R., W. G. Moldenhauer, and W. H. Wischmeier
1981 Transferability of U.S. technology for erosion prediction and control in the tropics. *In* Proc. Symposium on Soil Erosion and Conservation in the Tropics, American Society of Agronomy (Fort Collins, August 1979). Madison, WI: Soil Sci. Soc. Amer. Special Publ.

Foster, G. R., and W. H. Wischmeier
1974 Evaluating irregular slopes for soil loss prediction. Trans. Amer. Soc. Agric. Engin. 17(2):305-309.

Fournier, F.
1960 Climat et érosion. Paris: Presses Universitaires de France.
1962 Map of erosion danger in Africa south of the Sahara. Paris: EEC, Commission for Technical Cooperation in Africa.
1967 Research on soil erosion and soil conservation in Africa. Sols Africains 12:53-96.

Fox, J. W., and K. B. Cumberland, eds.
1962 Western Samoa: Land, life and agriculture in tropical Polynesia. Christchurch: Whitcombe and Tombs, Ltd.

Fredricksen, R. L.
1965 Sedimentation after logging road construction in a small western Oregon watershed. *In* Proc. Federal Inter-agency Sedimentation Conference, pp. 56-59. Misc. Publ. 970. Washington, DC: USDA.

Freire, O., and J. E. S. Pessotti
1974 Erodibilidade dos solos do estado de Sao Paulo. Anais da E. S. "Luis de Queiroz" 31:333-341. 1976 Erodibilidade dos solos de Piracicaba. Revista de Agricultura 51:195-202

Fullerton, C. M., and S. K. Wilson
1974 Some characteristics of Hawaiian high-intensity rainfall. Water Resour. Res. Center Technical Rep. no. 78. Honolulu: Univ. of Hawaii.

Ghose, S. K.
1971 Hydrological studies of recent floods and droughts in northeastern Brazil. Report no. 8, Sudene/DEMET/WMO. Recife: World Meteorological Organization.

Gilmour, D. A.
1977 Logging and the environment with particular reference to soil and stream protection in tropical rainforest situations. *In* FAO 1977*a*, pp. 225-235.

Gopinathan, B.
1977 Land use in hilly areas and development programs in Malaysia. *In* Proc. of International Workshop on Hilly Land Development, pp. 62-68. Los Banos: PCARR.

Greenland, D. J.
1971 Changes in the nitrogen status and physical condition of soils under pastures, with special reference to the maintenance of the fertility of Australian soils used for growing wheat. Soils and Fert. 34:237-251.
1974 Evolution and development of different types of shifting cultivation. *In* Soils Bull. no. 24: Shifting Cultivation and Soil Conservation in Africa, pp. 5-13. Rome: FAO.
1977 The magnitude and importance of the problem. *In* Greenland and Lal 1977, pp. 3-7.

Greenland, D. J., and R. Lal, eds.
1977 Soil conservation and management in the humid tropics. Chichester: Wiley.

Gulcur, M. Y.
1966 Watershed management in the Philippines. Paper presented at the Foresters' Conf., 2-3 Sept., at GSIS, Arroceros, Manila.

Gunn, R., and G. D. Kinzer
1949 Terminal velocity of water droplets in stagnant air. Jour. of Meteorology 6:243-248.

Guy, H. P.
1965 Residential construction and sedimentation at Kensington, MD. *In* ARS (Agricultural Research Service) Misc. Publ. 970, pp. 30-37. USDA.
1974 Remote sensing techniques for evaluation of urban erosion and sedimentation. IAHS-AISH Publ. no. 113:145-149.

Hansell, J. R. F., and J. R. D. Wall
1970 A preliminary report on the agricultural potential of the land systems of Guadalcanal, British Solomon Islands Protectorate. Misc. Report no. 92, Land Resources Division, Directorate of Overseas Surveys. Tolworth, Surrey, England.

Hardy, F.
1942 Soil erosion in Trinidad and Tobago. Trop. Agric. (Trinidad) 19(2):29-35.

Harrington, G. N., and D. Pratchett
1974 Stocking rate trials in Ankole, Uganda, 1: Weight gain of Ankole steers at intermediate and heavy stocking rates under different managements. Jour. of Agric. Sci. (UK) 82(3):497-503.

Hatch, T.
1981 Preliminary results of soil erosion and conservation trials under pepper *(Piper nigrum)* in Sarawak, Malaysia. *In* ICSC 1981, pp. 255-262.

Hattinger, H.
1976 Torrent control in the mountains with reference to the tropics. *In* Conservation Guide no. 2: Hydrological Techniques for Upstream Conservation, pp. 119-134. Rome: FAO.

Hauck, F. W.
1974 Introduction. *In* Shifting Cultivation and Soil Conservation in Africa. Soils Bull. no. 24, pp. 1-4. Rome: FAO.

Hawaii Agricultural Extension Service
1961 Hawaii: Soil and water conservation needs. The Hawaii Conservation Needs Committee, May 1961. Honolulu: CTAHR and SCS.

Hayes, W. A.
1977 Estimating water erosion in the field. *In* SCSA 1977, pp. 6-11.

Heede, B. H.
1977 Gully control structures and systems. *In* FAO 1977*a*, pp. 181-222.

Hernandez, C. C.
n.d. Vegetative control of soil erosion. Unpubl. paper from Forest Research Institute, Los Banos, Philippines.

Heusch, B.
1970 Une etude quantitative de l'erosion hydraulique dans les collines marneuses du pre-rif occidental. Estrait du rapport 1970, Tome 12. Rabat: Forest Research Station.
1980 Erosion in the Ader Dutchi Massif (Niger): An example of mapping applied to water and soil conservation. *In* De-Boodt and Gabriels 1980, pp. 521-529.
1981 Sociological constraints in soil conservation: A case study, the Rif Mountains, Morocco. *In* ICSC 1981, pp. 419-424.

Hill, I. D.
1966 Soil and land-use surveys, no. 19A: Antigua. Univ. of West Indies, Trinidad.

Hill, P. R.
1965 Africa—a simple system of management for soil and water conservation and drainage in mechanized crop production in the tropics. *In* Agricultural Development Paper no. 81, pp. 179-194. Rome: FAO.

Holeman, J. N.
1968 The sediment yield of major rivers of the world. Water Resourc. Res. no. 4:737-747.

Horton, R. E.
1945 Erosional development of streams and their drainage basins: Hydrological approach to quantitative morphology. Geological Soc. Amer. Bull. 56:275-370.

Hsu, S. C., T. V. Li, and C. S. Su
1977 Experiment on soil conservation practices for upland crops on slopeland. (First report.) Jour. Chinese Soil and Water Conserv. 8(2):91-104.

Htay, Aung
1971 Severe cyclonic storms responsible for flash flood in Pakokku and Monywa districts during the month of October 1967. *In* Forecasting Heavy Rains and Floods, (Joint training seminar, 1968), pp. 213-220. Kuala Lumpur: WMO.

Huat, Tan Eow
1974 Effects of simulated erosion on performance of maize *(Zea mays)* grown on Serdang colluvium. Soil Conservation and Reclamation Report no. 1. Kuala Lumpur: Ministry of Agriculture and Fisheries.

Hudson, N. W.
1957 Erosion control research. Progress report on experiments at Henderson Research Station, 1953-1956. Rhodesia Agric. Jour. 54(4):297-323.
1963 Raindrop size distribution in high intensity storms. Rhodesian Jour. of Agric. Res. no. 1, pp. 6-11.
1964*a* Field measurements of accelerated soil erosion in localized areas. Rhodesia Agric. Jour. 61(3):48, 60.
1964*b* The flour pellet method for measuring the size of raindrops. Res. Bull. no. 4. Salisbury, Rhodesia: Dept. of Conserv. and Extension.
1965 The influence of rainfall on the mechanics of soil erosion with particular reference to Southern Rhodesia. Unpublished M.S. thesis, University of Capetown.
1971 Soil conservation. Ithaca, NY: Cornell Univ. Press
1975 Field engineering for agricultural development. Oxford: Clarendon Press.
1978 Report on second consultancy mission to Sri Lanka, 11 December 1977 to 9 January 1978. Project: Reorganization of National Research Extension and Training Resources for Agriculture. Silsoe, England: National College of Agricultural Engineering. SRL/75/058.

1981 Social, political and economic aspects of soil conservation. *In* ICSC 1981, pp. 45-54.

Hudson, N., and D. C. Jackson
1959 Results achieved in the measurement of erosion and runoff in southern Rhodesia. Proc. Inter-African Soils Conference Compte Rendus 3:575-583.

Hurni, H.
1981 A nomograph for the design of labour-intensive soil conservation measures in rain-fed cultivations. *In* ICSC 1981, pp. 185-210.

IAHS (International Association of Hydrologic Science)
1974 Proc. Flash Floods Symposium (September). IAHS-AISH Publ. no. 112, Surrey, UK: Bartholomew Press for IAHS.

ICRISAT Farming Systems Staff
1977 Annual report of the farming systems research program, June 1976-May 1977. (Information report.) Hyderabad.

ICSC (International Conference on Soil Conservation)
1981 Soil conservation: Problems and prospects, R. P. C. Morgan, ed. Proc. Conservation 80 (Silsoe, UK, July 1980). Chichester: Wiley.

Ives, N. C.
1951 Soil and water runoff studies in a tropical region. Turrialba 1:240-244.

Jacks, G. V., and R. O. Whyte
1939 Vanishing lands: A world survey of soil erosion. New York: Doubleday, Doran.
1972 Published under the same title by Arno Press, New York.

Jackson, I. J.
1978 Climate, Water, and Agriculture in the Tropics. London: Longmans.

Jacot-Guillarmod, A.
1969 The effect of land usage on aquatic and semiaquatic vegetation at high altitudes in southern Africa. Hydrobiologia 34: 3-13.

Jalote, S. R., and O. P. Malik
1974 Farm forests of Rehmankhera. Soil Conserv. Dig. 2(2) 59-69.

JCRR-MARDB (Joint Commission on Rural Reconstruction and Mountain Agricultural Resources Development Bureau)
1977 Soil conservation handbook. Taipei, Taiwan.

Joshua, W. D.
1977 Soil erosive power of rainfall in the different climatic zones of Sri Lanka. *In* Erosion and Solid Matter Transport in Inland Waters. Proc. of Symp. Publ. no. 122, pp. 51-61. Paris: IAHS-AISH.

Jungerius, P. D.
1975 The properties of volcanic ash soils in dry parts of the Colombian Andes and their relation to soil erodibility. Catena 2(1/2):69-80.

Keech, M. A.
1968 Soil erosion survey techniques. Proc. and Trans., Rhodesian Scient. Assoc. 53: 13-16.

Keng, D. C. S., and C. K. Koon
1972 Flood control and water conservation works in Bukit Timah catchment, Singapore. *In* Water Resources Environment and National Development, vol. 2, pp. 26-43. Science Council of Singapore and US National Academy of Sciences.

Kinnell, P. I. A.
1973 The acoustic measurement of water-drop impact. Jour. of Applied Meteorology 11(4):691-694.

Kinoshita, T., and Y. Yamazaki
1975 Increase of sediment transport due to large-scale urbanization. *In* Publ. no. 113, pp. 127-129. Paris: IAHS-AISH.

Klingebiel, A. A., and P. H. Montgomery
1961 Land capability classification. USDA Handbook no. 210. Washington, DC.

Kohnke, H., and A. R. Bertrand
1959 Soil Conservation. New York: McGraw-Hill.

Kowal, J.
1970 The hydrology of a small catchment basin at Samaru, Nigeria, IV: Assessment of soil erosion under varied land management and vegetative cover. Nigerian Agric. Jour. 7.134-147.

Kowal, J. M., and A. H. Kassam
1976 Energy load and instantaneous intensity of rainstorms at Samaru, northern Nigeria. Trop. Agric. 53(3):185-197.

Krantz, B. A., J. Kampen, and S. M. Virmani
1978 Soil and water conservation and utilization for increased food production in the semiarid tropics. Hyderabad: ICRISAT, for the Congress of the 11th International Society of Soil Science (Edmonton, Canada, 22 June).

Kulandaiswamy, V. C., A. Mohanakrishnan, G. S. Jakhade, K. R. Chandrasekhavan, and P. Kumaraswamy
1973 Flood estimation, forecasting, and control. Paper read at International Seminar on Hydraulics of Alluvial Streams, New Delhi, 15-19 January.

Kunkle, S. H., and D. A. Hatcharik
1977 Conservation of upland wildlands for downstream agriculture. *In* FAO 1977*b*, pp. 133-149.

Kundstadter, P., E. C. Chapman, and S. Sabhasri, eds.
1978 Farmers in the Forest: Economic development and marginal agriculture in northern Thailand. Honolulu: Univ. Press of Hawaii for the East-West Center.

Lal, R.
1974 Soil erosion and shifting agriculture. *In* Soils Bull. no. 24, Shifting Cultivation and Soil Conservation in Africa, pp. 48-71. Rome: FAO.
1975 Role of mulching techniques in tropical soil and water management. Tech. Bull. no. 1. Ibadan, Nigeria: IITA.
1976*a* No-tillage effect on soil properties under different crops in western Nigeria. Soil Sci. Soc. Amer. Jour. 40(5): 762-768.
1976*b* Soil erosion on Alfisols in western Nigeria, II: Effects of mulch rates. Geoderma 16:377-387.
1976*c* Soil erosion on Alfisols in western Nigeria, III: Effects of rainfall characteristics. Geoderma 16:389-401.
1976*d* Soil erosion problems on an Alfisol in western Nigeria and their control. Monograph no. 1. Ibadan: IITA.
1977*a* Analysis of factors affecting rainfall erosivity and soil erodibility. *In* Greenland and Lal 1977, pp. 49-56.
1977*b* Soil-conserving versus soil-degrading crops and soil management for erosion control. *In* Greenland and Lal 1977, pp. 81-86.
1977*c* A brief review of erosion research in the humid tropics of Southeast Asia. *In* Greenland and Lal 1977, pp. 203-212.
1977*d* Review of soil erosion research in Latin America. *In* Greenland and Lal 1977, pp. 213-240.
1981 Soil conservation: Preventive and control measures. *In* ICSC 1981, pp. 175-181.

Lal, V. B., and S. Banerji
1974 Man's impact on erosion in the rural environment: The Indian experience. *In* Publ. no. 113, pp. 46-52. Paris: IAHS-AISH.

Lamb, D., and E. Beibi
1977 The effects of logging operations on stream turbidity levels in the rain forests of the Gogol Valley. Tropical Forestry Research Note Sr. 36. Buroko, Papua New Guinea: Office of Forests.

Lamb, H. H.
1972 Climate—present, past and future, vol. 1: Fundamentals and climate now. London: Methuen.

Lang, D. M.
1967 Soil and land-use surveys no. 21: Dominica. Univ. of West Indies, Trinidad.

Lang, D. M., and D. M. Carroll
1966 Soil and land-use surveys no. 16: St. Kitts and Nevis. Univ. of West Indies, Trinidad.

Langbein, W. B., and S. A. Schumm
1958 Yield of sediment in relation to mean annual precipitation. Trans. Amer. Geophys. Un. 39(6).1076-1084.

Laws, J. O.
1941 Measurements of fall-velocity of water-drops and raindrops. Trans. Amer. Geophys. Un. 22.709-712.

Laws, J. O., and D. A. Parsons
1943 The relation of raindrop size to intensity. Trans. Amer. Geophys. Un. 24.452-459.

Le Bourdiec, P.
1972 Accelerated erosion and soil degradation. Monogr. Biol. 21 227-260.

Leigh, C. H., and K. S. Low
1973 An appraisal of the flood situation in west Malaysia. *In* Proc. Symp. Biol. Res. and Nat. Dev., pp. 57-72. Kuala Lumpur: Univ. of Malaysia, Dept. of Geography.

Lester-Smith, W. C.
1938 Soil erosion on tea estates and some suggestions for its control. Trop. Agric. 91 280-285.

Lombardi Neto, F.
1977 Rainfall erosivity—its distribution and relationship with soil loss at Campinas, Brazil. M.S. thesis, Purdue University.

Lombardi Neto, F., and J. Bertoni
1975 Tolerancia de perdas de terra para solos do Estado de Sao Paulo. Bol. Tec. Inst. Agron. 28:1-12.

Lopez Saucedo, M.
1975 Solo la sexta parte del pai sin erosion. Mex For. 49(2):27-28.

Low, F. K.
1967 Estimating potential erosion in developing countries. Jour. of Soil and Water Conserv. 22:147-148.

Low, K. S.
1972 Interception loss in the humid forested areas (with special reference to Sungai Lui catchment, west Malaysia). Malay Nat. Jour. 25(2):104-111.

Lowdermilk, W. C.
1953 Conquest of the land through seven thousand years. Agric. Information Bull. no. 99, Washington, DC: USDA.

Lugo-Lopez, M. A.
1969 Prediction of the erosiveness of Puerto Rican soils on a basis of the percentage of particles of silt and clay when aggregated. Jour. Agric. Univ. Puerto Rico 53:187-190.

McComb, A. L., and H. Zakaria
1971 Soil erosion in Upper Solo River basin, central Java. Rimba Indonesia 16(1/2): 20-27.

McCormack, D. E., and K. K. Young
1981 Technical and societal implications of soil loss tolerance. *In* ICSC 1981, pp. 365-376.

McElroy, A. D., S. Y. Chiu, J. W. Nelgen, A. Aleti, and F. W. Bennett
1976 Loading functions for assessment of water pollution from nonpoint sources. Environmental protection Technology Series EPA-600/2-76-151. Washington, DC: US Environmental Protection Agency.

Macias, G. B., and G. R. Cervantes
1966 La conservacion del suelo y el agua en Mexico. Instituto Mexicano de Recursos Naturales Renovables, A. C. Mexico, D. F. (Distrito Federal).

Maher, C.
1972 Soil conservation 1: The fight against erosion. World Crops 24(2):94-97.

Mannering, J. V.
1981 The use of soil loss tolerances as a strategy for soil conservation. *In* ICSC 1981, pp. 337-349.

Maude, A.
1970 Shifting cultivation and population growth in Tonga. Jour. of Trop. Geogr. 31:57-64.

Megahan, W. F.
1977 Reducing erosional impacts of roads. *In* FAO 1977*a*, pp. 237-261.

Meijer, W.
1973 Devastation and regeneration of lowland Dipterocarp forests in Southeast Asia. BioScience 23(9):528-532.

Metzner, J. K.
1976 Lamptoronisasi: An experiment in soil conservation. Bull. of Indonesian Economic Studies 12(1):103-109.

Meyer, L. D.
1981 Modelling conservation practices. *In* ICSC 1981, pp. 31-44.

Meyer, L. D., and D. L. McCune
1958 Rainfall simulator for runoff plots. Jour. Amer. Soc. Agric. Eng. 39(10):644-648.

Meyer, L. D., G. R. Foster, and M. J. M. Romkens
1975 Source of soil eroded by water from upland slopes. ARS Report, ARS-S40, pp. 177-189. Washington, DC: USDA.

Middleton, H. E.
1930 Properties of soils which influence soil erosion. Tech. Bull. no. 178. Washington, DC: USDA.

Mihara, H.
1959 Raindrops and soil erosion. Bull. of National Inst. of Agric. Ser. A, 1:48-51.

Miller, A., and J. C. Thompson
1975 Elements of meteorology. Columbus, OH: Merrill.

Milsum, J. N., and E. A. Curtler
1925 *Calopogonium mucunoides*. Malaysian Agric. Jour. 13:271-272.

Miranda, S. M.
1978 Baseline information on soil erosion in the Philippines. Unpublished literature on the current status of knowledge on soil erosion, collated and enclosed with private correspondence.

Mitchell, J. K., and G. D. Bubenzer
1980 Soil loss estimation. *In* Soil Erosion, M. J. Kirby and R. P. C. Morgan, eds. Pp. 17-62. Chichester: Wiley.

Moazzam, S. M.
1971 Heavy rainfall and associated floods in West Pakistan, 1971. *In* Forecasting of Heavy Rains and Floods (joint seminar, 1968), pp. 267-268. Kuala Lumpur: WMO.

Moberg, J. P.
1972 Some soil fertility problems in the West Lake region of Tanzania, including the effects of different forms of cultivation on the fertility of some ferralsols. East African Agric. and For. Jour. 37:35-46.

Moldenhauer, W. C.
1980 Soil erosion—a global problem. *In* DeBoodt and Gabriels 1980, pp. 3-8.

Moldenhauer, W. C., and G. R. Foster
1981 Empirical studies of soil conservation techniques and design procedures. *In* ICSC 1981, pp. 13-29.

Morgan, G. W., and R. Baker
1967 Soil and land-use surveys no. 23: Jamaica, Parish of St. Thomas, Univ. of West Indies, Trinidad.

Morgan, R. P. C.
1974 Estimating regional variations in soil erosion hazard in Peninsular Malaysia. Malay Nat. Jour. 28(2):94-106.

Morgan, R. P. C., and D. D. V. Morgan
1981 Problems of validating a Meyer-Wischmeier type soil erosion model with field data. *In* ICSC 1981, pp. 327-334.

Mueller-Dombois, D.
1973 A nonadapted vegetation interferes with water removal in tropical rain forest in Hawaii. Trop. Ecol. 14(1):1-18.

Murphy, R. S., and H. S. Shankaranarayana
1977 Utility of soil maps for watershed treatment in the Siwaliks. Jour. Ind. Soil Sci. Soc. 25(2):313-316.

Murray-Rust, D. H.
1972 Soil erosion and reservoir sedimentation in a grazing area west of Arusha, northern Tanzania. Geografiska Annaler 54A: 325-343.

Musgrave, G. W.
1947 The quantitative evaluation of factors in water erosion, a first approximation. Jour. Soil and Water Conserv. 2:133-138.

Mutchler, C. K., and C. E. Murphree
1981 Prediction of erosion on flatlands. *In* ICSC 1981, pp. 321-325.

Nabhan, G. P., and T. E. Sheridan
1977 Fence rows of the Rio San-Miguel, Sonora, Mexico. Human Ecol. 5(2):97-111.

Nadel, G.
1976 Guatemala. Atlantic Monthly, July.

NAS (National Academy of Sciences)
1977 Leucaena, promising forage and tree crop for the tropics. Washington, DC.
1979 Tropical legumes: resources for the future. Washington, DC.

NESK (National Environment Secretariat of Kenya)
1976 The incidence of soil erosion in Kenya. Report of the Subcommittee on the Natural Environment. Nairobi: Office of the President.

Nye, P. H., and D. J. Greenland
1960 The soil under shifting cultivation. Tech. Communication no. 51. Reading, UK: Lamport Gilbert for Commonwealth Bureau of Soils, Harpendon.

Obeng, H. B.
1973 Problems of soil erosion in cereal crop production in Ghana. Sols Africains 17:75-83.

Ochse, J. J., J. Soule, M. J. Dijkman, and C. Wehlburg
1961 Tropical and subtropical agriculture, vol. 1. London: Macmillan.

Ofori, C. S.
1974 The effect of ploughing and fertilizer application on yield of cassava (*Manihot esculenta Crantz*) Ghana Jour. of Agric. Sci. 6(1):21-24.

Okigbo, B. M.
1977 Farming systems and soil erosion in West Africa. *In* Greenland and Lal 1977, pp. 151-163.

Oliveira, B.
1970 Vale do Paraiba e Guanabara Numa area de erosao grave. Bras. Forestal 1(3): 42-50.

Olson, T. C., and W. H. Wischmeier
1963 Soil erodibility evaluations for soils on the runoff and erosion stations. Proc. Soil Sci. Soc. Amer. 27(5):590-592.

Onyeagocha, S. C.
1975 The establishment of vegetative cover on wastelands in southern parts of Nigeria with particular reference to East Central

State. Forestry Commission Workshop. Enugu: IITA.

Othieno, C. O.
1975 Effect of ground cover by the tea canopy on soil erosion. Tea in East Africa 15(2):8.

Pacheco, E., T. Silva, H. Santos, R. Feldman, and S. Teixeira
1975 Efeito do manejo de um latassol vermelho amarelo, fase cerrado, sobre o crescimento e producao da larenjeira (*Citrus sinensis* Osbeck Cv. "Baianinha"). Experientiae 19(10):211-238.

Panabokke, C. R.
1977 Erosion hazard and farming systems in the humid tropics of south Asia. *In* Greenland and Lal 1977, pp. 213-219.

Partosedono, R. S.
1977 Effects of man's activities on erosion in rural environments and a feasibility study for rehabilitation. *In* Publ. no. 113, pp. 53-56. Paris: IAHS-AISH.

Patnaik, N.
1975 Soil erosion: A menace to the nation. Indian Farming 24(11):7-10.

Patric, J. H., and L. K. Brink
1977 Soil erosion and its control in the eastern forest. *In* SCSA 1977, pp. 362-368.

PCARR (Philippine Council for Agriculture and Resources Research)
1977 Annual report. Watershed and Range Research Division.

Pendleton, R. L.
1940 Soil erosion in the tropics. Jour. For. 38(10):753-762.

Pereira, H. C.
1956 A rainfall test for structure of tropical soils. Jour. Soil Sci. 7(1):68-75.
1973 Land use and national resources. Cambridge University Press.

Pimentel, D., and M. Pimentel
1979 Food, energy and society. London: Arnold.

Pimentel, D., E. C. Terhune, R. Dyson-Hudson, S. Rochereau, R. Samis, E. A. Smith, D. Denman, D. Reifschneider, and M. Shephard
1976 Land degradation effects on food and energy resources. Sci. 194(4261):149-155.

Pinczés, Z., A. Kerényi, K. Erdös-Marton, and P. Csorba
1981 Judgement of the danger of erosion through the evaluation of regional conditions. *In* ICSC 1981, pp. 87-103.

Pla, I.
1977 Soil erosion in the humid tropics of Latin America with particular reference to Venezuela. *In* Greenland and Lal 1977, pp. 251-257.

Pla Sentis, I.
1981 Soil characteristics and erosion risk assessment of some agricultural soils in Venezuela. *In* ICSC 1981, pp. 123-138.

Popenoe, H.
1976 Soil conservation in Central America and Panama: Current problems. Revista de Biologia Tropical 24:79-82.

Price, R. W.
1960 Soil and land-use surveys no. 12: Jamaica, Parish of Hanover. Univ. of West Indies, Trinidad.

Prieto Bolivar, J.
1951 Vision general del problema de la erosion en Colombia. Agric. Tropical (Bogota) 7(9):52-54.

Ralph, K. A.
1975 Perception and adjustment to flood in the Meghna Flood plain. M.S. thesis, University of Hawaii.

Rapp, A.
1975 Soil erosion and sedimentation in Tanzania and Lesotho. Ambio 4(4):154-163.
1977*a* Methods of soil erosion monitoring for improved watershed management in Tanzania. *In* FAO 1977*a*, pp. 85-98.
1977*b* Soil erosion and reservoir sedimentation —case studies in Tanzania. *In* FAO 1977*b*, pp. 123-132.

Rapp, A., V. Axelsson, L. Berry, and D. H. Murray-Rust
1972 Soil erosion and sediment transport in the Morogoro River catchment, Tanzania. Geografiska Annaler 54A:125-155.

Rapp, A., D. H. Murray-Rust, C. Christiansson, and L. Berry
1972 Soil erosion and sedimentation in four catchments near Dodoma, Tanzania. Geografiska Annaler 54A:255-318.

Rice, R. M.
1977 Forest management to minimize landslide risk. *In* FAO 1977*a*, pp. 271-287.

Riquier, J.
1977 Philosophy of the world assessment of soil degradation and items for discussion. *In* FAO 1977*c*, pp. 36-38.
1980 Small-scale mapping of present and potential erosion. *In* DeBoodt and Gabriels 1980, pp. 23-28.

Roche, L.
1974 The practice of agri-silviculture in the tropics with special reference to Nigeria. *In* Shifting Cultivation and Soil Conservation. Soils Bull. no. 24, pp. 179-190. Rome: FAO.

Rochl, J. W.
1962 Sediment source area delivery ratios and influencing morphological factors. *In* Publ. no. 59. Proc. Symp. (Bari, Italy), pp. 202-213. Gentbrugge, Belgium: IASH.

Roose, E. J.
1973 Dix-sept annees de mesures experimentales de l'erosion et du ruissellement au Senegal. L'Agronomie Tropical 22: 123-152.
1975*a* Erosion et ruissellement en Afrique de l'ouest. Vingt annees de mesures en petites parcelles experimentales. Abidjan: ORSTOM.
1975*b* Natural mulch or chemical conditioners for reducing soil erosion in humid tropical areas. *In* Spec. Publ. no. 7, pp. 131-138. Madison, WI: Soil Sci. Soc. Amer.
1977*a* Application of the universal soil-loss equation of Wischmeier and Smith in West Africa. *In* Greenland and Lal 1977, pp. 177-187.
1977*b* Erosion et ruissellement en Afrique de l'ouest. Vingt annees de mesures en petites parcelles experimentales. Paris: ORSTOM.
1977*c* Use of the universal soil-loss equation to predict erosion in west Africa. *In* SCSA 1977, pp. 60-74.

Rose, C. W.
1958 Effects of rainfall and soil factors on soil detachment and the rate of water penetration into soils. Ph.D. thesis, Univ. of London.
1960 Soil detachment caused by rainfall. Soil Sci. 89(1):28-35.
1961 Rainfall and soil structure. Soil Sci. 91:49-54.

Roth, C. B., D. W. Nelson, and M. J. M. Romkens
1974 Prediction of subsoil erodibility using chemical, mineralogical, and physical parameters. EPA-660/2-74-043. Washington, DC: U.S. Environmental Protection Agency, Office of Research and Development.

RRIM (Rubber Research Institute of Malaysia)
1977 *Mucuna cochinchinensis*—A potential short term legume cover plant. Planters' Bull. no. 150:78-82.

Ruthenberg, H.
1971 Farming systems in the tropics. Oxford: Clarendon Press.

Sachdeve, C. P., B. S. Gill, Y. Dutta, and M. M. Daniel
1976 Comparison of a few sward-forming grasses for their effectiveness in stabilization of waterways. Indian Forester 102(1):37-42.

Sanchez, P. A.
1976 Properties and management of soils in the tropics. New York: Wiley.

Schroeder, T. A.
1976 Meteorological aspects of the Oahu flood of 19 April 1974. Technical Report no. 97, UHMET 76-03. Honolulu: Water Resources Research Center, Univ. of Hawaii.

Schwab, G. O., G. S. Taylor, J. L. Fouss, and E. Stibbe
1966 Crop response from tile and surface drainage. Proc. Soil Sci. Soc. Amer. 30:631-637.

SCS (Soil Conservation Service, USDA)
1948 Guide for soil conservation surveys. Washington, DC: Govt. Printer.
1971 Construction and conservation. HA. 7-2-1400-251. Honolulu: USDA.
1975*a* Engineering field manual. Washington, DC: USDA.
1975*b* Soil taxonomy: A basic system of soil classification for making and interpreting soil surveys. Agric. Handbook no. 436. Washington, DC: USDA.
1976 Erosion and sediment control guide for urbanizing areas in Hawaii. Washington, DC: USDA.

SCSA (Soil Conservation Society of America)
1973 Conservation tillage. Proc. nat'l. conf. Ankeny, IA.

1976 Resource conservation glossary. Ankeny, IA.
1977 Soil erosion: Prediction and control. Spec. Publ. no. 21. Ankeny, IA.

Seavoy, R. E.
1975 The origin of tropical grasslands in Kalimantan, Indonesia. Jour. Trop. Geogr. 40:48-52.

Semple, A. T.
1971 Grassland improvement in Africa. Biol. Conserv. 3(3):173-180.

Serrano, R. C., and M. P. L. Suan
1976 Soil erosion: Worsening problem in the Philippines. Canopy 2(12):15,18,20.

Shalash, M. S. E.
1977 Erosion and solid matter transport in inland waters with reference to the Nile basin. IAHS-AISH Publ. no. 122:278-288.

Shankarnarayan, K. A., and M. L. Magoon
1974 Prevent soil erosion the grass way. Indian Farming 24(8):13-14.

Sharma, S. G., R. N. Gupta, and K. S. Panwar
1976 Concept of crop protection factor evaluation in soil erosion. Indian Jour. Agric. Res. 10(3):145-152.

Shaxson, T. F.
1981a Developing concepts of land husbandry for the tropics. *In* ICSC 1981, pp. 351-362.
1981b Reconciling social and technical needs in conservation work on village farmlands. *In* ICSC 1981, pp. 385-397.

Sheng, T. C.
1977a Protection of cultivated slopes. *In* FAO 1977a, pp. 147-149.
1977b Wattling and staking. *In* FAO 1977a, pp. 289-293.
1982 Erosion problems associated with cultivation in humid tropical hilly regions. *In* Soil Erosion and Conservation in the Tropics. ASA Special Publ. No. 43, pp. 27-39, American Society of Agronomy, Madison, WI.

Sheng, T. C., and H. R. Stennett
1975 Forestry development and watershed management in the upland regions—Jamaica. FAO Working Document SF/JAM 505. Rome: FAO-UNDP.

Sien, C. L., and C. K. Koon
1971 The record floods of 10 December 1969 in Singapore. Jour. Trop. Geogr. 33:9-19.

Siew, Thein Kim, and Chin Fatt
1976 Effects of simulated erosion on performance of maize (*Zea mays*) grown on Durian series. Soil Conservation and Reclamation Report no. 3. Kuala Lumpur: Ministry of Agriculture.

Singer, M. J., J. Blackard, and P. Janitsky
1980 Dithionite iron and soil cation content as factors in soil erodibility. *In* DeBoodt and Gabriels 1980, pp. 259-267.

Singh, A.
1974 Selection of structures for soil and water conservation. Soil Conserv. Digest 2(2): 49-53.

Singh, P., A. S. Ramanathan, and V. G. Ghaneker
1974 Flash floods in India. IAHS-AISH Publ. no. 112:114-118.

Singh, V. P., I. T. Corpuz, and T. Wickhan
1976 Improving the productivity of exposed subsoils in Talavera, Nueva Ecija. IRRI Saturday seminar, 4 Sept., 1976, Los Banos, The Philippines. Unpublished.

Smith, D. D.
1941 Interpretation of soil conservation data for field use. Agric. Eng. 22:173-175.

Smith, D. D., and W. H. Wischmeier
1957 Factors affecting sheet and rill erosion. Trans. Amer. Geophys. Un. 38(6):889-896.

Smith, R. M., and S. Abruna
1955 Soil and water conservation research in Puerto Rico 1938-1947. Bull. 124. Rio Piedras: Puerto Rico Agric. Sta.

Smith, R. M., and W. L. Stamey
1965 Determining the range of tolerable erosion. Soil Sci. 100(6):414-424.

Soemarwoto, O.
1974 The soil erosion problem in Java. *In* Proc. First International Cong. of Ecology (Sept. 8-14), pp. 361-364. The Hague.

Soliman, M. M.
1974 Urbanization and the processes of erosion and sedimentation in the River Nile. IAHS-AISH Publ. no. 113:123-126.

Soong, N. K., and C. S. Yeoh
1975 Latex-oil emulsions for controlling soil erosion on exposed soil surfaces. (Preprint). Int. Rubber Conf. Kuala Lumpur.

Speer, W. S.
1963 Report to the government of Malaysia on soil and water conservation. Report no. 1788, Project TA/MAL/LA. Rome: FAO.

Stark, J.
1963 Soil and land-use surveys no. 14: Jamaica, Parish of St. Elizabeth. Univ. of West Indies, Trinidad.
1964a Soil and land-use surveys no. 15: Jamaica, Parish of Westmoreland. Univ. of West Indies, Trinidad.
1964b Soil and land-use surveys no. 17: Jamaica, Parish of Manchester. Univ. of West Indies, Trinidad.

Stark, J., P. Lajoie, and A. T. Green
1966 Soil and land-use surveys no. 20. St. Lucia. Univ. of West Indies, Trinidad.

Stocking, M. A.
1971 Soil erosion problems in Rhodesia. Jour. Soil and Water Conserv. 26:239-240.
1972 Aspects of the role of man in erosion in Rhodesia. Zambia 2(2):1-10.
1976 Tunnel erosion. Rhodesia Agric. Jour. 73(2):35-39.
1981 Conservation strategies for less developed countries. *In* ICSC 1981, pp. 377-384.

Stocking, M. A., and H. A. Elwell
1973a Prediction of subtropical storm soil losses from field plot studies. Agric. Meteorology 12(2):193-201.
1973b Soil erosion hazard in Rhodesia. Rhodesian Agric. Jour. 70:93-96.
1976 Rainfall erosivity over Rhodesia. Trans. Inst. Br. Geogr. 1(2):231-245.

Stone, B.
1975 Windera soil conservation problems. Trop. Grasslands 9(1):70-71.

Sturtz, J. D., P. G. Harrison, and L. Falvey
1975 Regional pasture development and associated problems, II: Northern Territory. Trop. Grasslands 9(2):83-91.

Suarez de Castro, F.
1950 Relaciones entre las lluvias y la erosion. Agric. Trop. (Bogota) 6:45-47.
1951a Experimentos sobre la erosion de los suelos; resumen de los resultados obtenidos en algunas investigaciones sobre conservacion de suelos y agua duvante los anos de 1949 y 1950. Boletin Tecnico no. 6 del Centro Nol. de Investigaciones de Cafe. Chinchina, Caldas.
1951b Influencia de la erosion sobre la productibilidad de los terranos. Agric. Trop. (Bogota) 7(5):42-43.
1952 Perdidas de suelo por erosion. Agric. Trop. (Bogota) 8(9):35-37.

Szechowycz, R. W., and M. M. Qureshi.
1973 Sedimentation in Mangla Reservoir. Proc. Amer. Soc. Civil Engineers Jour. of the Hydraulics Div. 99:1551-1572.

Tan Hoe Tim
1971 The problem of flood prediction on the East Coast of Malaysia. *In* Forecasting of Heavy Rains and Floods, pp. 253-258. Joint training seminar, 1968. Kuala Lumpur: WMO.

Taylor, R. C.
1973 An atlas of Pacific Islands rainfall. Data Report no. 25. Honolulu: Hawaii Institute of Geophysics.

TCNSPC (Technical Committee on Nonpoint Source Pollution Control)
1978 Nonpoint source pollution in Hawaii: Assessment and recommendations. Tech. Rep. no. 2. Honolulu.

Tempany, H. A., and D. H. Grist
1958 An introduction to tropical agriculture. London: Longmans, Green and Co.

Temple, P. H.
1972a Soil and water conservation policies in the Uluguru Mountains, Tanzania. Geografiska Annaler 54A:110-123.
1972b Measurements of runoff and soil erosion at an erosion plot scale, with particular reference to Tanzania. Geografiska Annaler 54A:203-220.

Temple, P. H., and D. H. Murray-Rust
1972 Sheet wash measurements on erosion plots at Mfombwe, eastern Uluguru Mountains, Tanzania. Geografiska Annaler 54A:195-202.

Temple, P. H., and A. Rapp
1972 Landslides in the Mgeta area, western Uluguru Mountains, Tanzania. Geografiska Annaler 54A:157-193.

Temple, P. H., and A. Sundberg
1972 The Rufiji River, Tanzania: Hydrology and sediment transport. Geografiska Annaler 54A:345-368.

Teoh, T. S.
1971 Where does all the rainfall go? Planters Bull. of Rubber Res. Inst. of Malaysia 115:215-219.

Thijsse, J. B.
1976 Deforestation and erosion in mountain areas of Java. Bioindonesia no. 2:33-42.

Thomas, A.
1967 Farming in hot countries. London: Faber and Faber.

Thornes, J. B.
1981 Conservation practices in erosion models. *In* ICSC 1981, pp. 265-271.

Troll, C.
1966 Seasonal climates of the earth. World maps of climatology. Berlin: Springer Verlag.

Turvey, N. D.
1974 Nutrient cycling and variations in stream water quality under tropical rain forest in central Papua. Occasional Paper no. 10. Port Moresby: Univ. of Papua New Guinea, Dept. of Geography.

Uehara, G.
1974 The composition of Mekong river silt and its possible role as a source of plant nutrient in delta soils. Report submitted to Committee for Coordination of Investigations of the Lower Mekong Basin. Honolulu: Univ. of Hawaii, Dept. of Agronomy and Soil Science.
1977 An overview of the soils of the arable tropics *In* Proc. Workshop on Exploiting the Legume, *Rhizobium symbiosis*, pp. 67-80. Honolulu: Univ. of Hawaii, NIFTAL Project.

UN (United Nations)
1977 Statistical Yearbook. Issue 28. New York.

University of Nairobi
1977 An evaluation study of the Machakos manual terracing programme. Special report of a study carried out by the departments of Sociology and Agricultural Engineering. Nairobi.

Uppal, H. L., and S. R. Sehgal
1956 The unprecedented floods of October 1955 in Punjab and a discussion of measures to deal with the same. IAHS-AISH Publ. no. 42:14-21.

USDA (United States Department of Agriculture)
1973 Farmers Bulletin no. 2171. Washington, DC: Govt. Printer.

USDA Soil Survey Staff
1951 Soil Survey Manual. Agric. Handbook no. 18. Washington, DC: Govt. Printer.

Valentin, C., and E. J. Roose
1981 Soil and water conservation problems in pineapple plantations of south Ivory Coast. *In* ICSC 1981, pp. 239-246.

Van der Weert, R.
1974 Influence of mechanical forest clearing on soil conditions and the resulting effects on root growth. Trop. Agric. (Trinidad) 51(2):325-331.

Van Zinderen-Bakker, E. M., and M. J. A. Werger
1974 Environment, vegetation and phytogeography of the high-altitude bogs of Lesotho. Vegetatio 29:37-49.

Vaudrey, W. C.
1963 Floods of March-May 1963 in Hawaii. Open-file report. Honolulu: USGS Water Resource Div.

Verduzco, J.
1960 Reforestacion de torrenos forestales degradados. Proc. Fifth World Forestry Cong. 3:1981-1983.

Verma, T. R.
1968 Legumes in soil conservation. Jour. Soil and Water Conserv. in India 16(1/2): 65-68.

Vermeer, D. E.
1970 Population pressure and crop rotational changes among the Tiv of Nigeria. Annals Assoc. Amer. Geogr. 60(2):299-314.

Vernon, K. C., and D. M. Carroll
1965 Soil and land-use surveys no. 18: Barbados. Univ. of West Indies, Trinidad.

Viets, F. G., Fr.
1965 The plant's need for and use of nitrogen. *In* Soil Nitrogen, eds., W. V. Bartholomew and F. E. Clark, pp. 503-549. Agronomy Series no. 10. Madison, WI: ASA.

Virgo, K. J., and D. A. Holmes
1977 Soil and landform features of mountainous terrain in South Thailand. Geoderma 18(3):207-225.

Virgo, K. J., and R. N. Munro
1978 Soil and erosion features of the Central Plateau region of Tigrai, Ethiopia. Geoderma 20(2):131-157.

Walter, P. J. G.
1971 Fundamentals of erosion control. Turnoff 3(1):9-16.

Walters, M. M.
1955 Erosion—a method for its determination, with special reference to the mixed karoo. Farming in South Africa, June:287-290.

Ward, R. G.
1965 Land use and population in Fiji. London: Her Majesty's Stationery Office.

Warnock, R. G., and R. G. Lagoke
1974 Suspended sediments from urban development. IAHS-AISH Publ. no. 113:119-122.

Watson, J. P., and J. Spector
1958 Soil and land-use surveys no. 3: St. Vincent. Univ. of West Indies, Trinidad.

Watters, R. F.
1971 Shifting cultivation in Latin America. Forestry Development Paper no. 17. Rome: FAO.

Weidelt, H. J., compiler
1975 Manual of reforestation and erosion control for the Philippines. Eschborn, West Germany: German Agency for Tech. Coop. Ltd.

Wiggins, S. L.
1981 The economics of soil conservation in the Acelhuate River Basin, El Salvador. *In* ICSC 1981, pp. 399-417.

Wilkinson, G. E.
1975 Rainfall characteristics and soil erosion in the rainforest area of western Nigeria. Exp. Agric. 11:247-255.

Wilkinson, G. E., and P. O. Aina
1976 Infiltration of water into two Nigerian soils under secondary forest and subsequent arable cropping. Geoderma 15:51-59.

Wischmeier, W. H.
1973 Conservation tillage to control water erosion. *In* SCSA 1973, pp. 133-141.
1976*a* Cropland erosion and sedimentation. *In* Control of Water Pollution from Cropland, vol. 2, pp. 31-57. ARS-H-5-2. Washington, DC: USDA.
1976*b* Use and misuse of the universal soil loss equation. Jour. Soil and Water Conserv. 31(1):5-9.

Wischmeier, W. H., C. B. Johnson, and B. V. Cross
1971 A soil erodibility nomograph for farmland and construction sites. Jour. of Soil and Water Conserv. 26(5):189-193.

Wischmeier, W. H., and J. V. Mannering
1969 Relation of soil properties to its erodibility. Proc. Soil Sci. Soc. Amer. 33(1): 131-137.

Wischmeier, W. H., and D. D. Smith
1958 Rainfall energy and its relationship to soil loss. Trans. Amer. Geophys. Un. 39(2):285-291.
1961 A universal soil-loss estimating equation to guide conservation farm planning. Trans. 7th Cong. Internat. Soil Sci. Soc. 1:418-425.
1962 Rainfall erosion. Advances in Agronomy 14:109-148.
1965 Predicting rainfall-erosion losses from cropland east of the Rocky Mountains. Agric. Handbook no. 282. Washington, DC: USDA.
1978 Predicting rainfall-erosion losses—a guide to conservation planning. Agric. Handbook no. 537. Washington, DC: USDA.

Wittmus, H. D., G. B. Triplett, Jr., and B. W. Greb
1973 Concepts of conservation tillage systems using surface mulches. *In* SCSA 1973, pp. 5-12.

WMO (World Meteorological Organization)
1970 Forecasting of heavy rains and floods. *In* Proc. Joint Training Seminar (11-23 November 1968). Kuala Lumpur.

Wolman, M. G., and A. P. Schick
1967 Effects of construction on fluvial sediment, urban and suburban areas of Maryland. Water Resour. Res. 3(2):451-464.

Wood, H. B.
1977 Hydrologic differences between selected forested and agricultural soils in Hawaii. Jour. Soil Sci. Soc. Amer. 41(1):132-136.

Wright, Madison, J., ed.
1976 Plant adaptation to mineral stress in problem soils. *In* Proc. Workshop (National Agricultural Library, Beltsville, MD).

Spec. Publ. Ithaca, NY: Cornell Univ. Agric. Expt. Sta.

Yamamoto, T., and H. W. Anderson
1973 Splash erosion related to soil erodibility indexes and other forest soil properties. Water Resour. Res. 9(2):336-345.

Young, A.
1977 Traditional forms of land use in relation to soil erosion. *In* FAO 1977*b*, pp. 51-58.

Young, H. M., Jr.
1973 Acceptance of conservation tillage. *In* SCSA 1973, pp. 219-221.

Young, K. K.
1980 The impact of erosion on the productivity of soils in the United States. *In* DeBoodt and Gabrieis 1980, pp. 295-303.

Zingg, A. W.
1940 Degree and length of land slope as it affects soil loss in run-off. Agric. Eng. 21:59-64.

Lal, R. 1979. Physical characteristics of soils of the tropics: Determination and management. In Soil physical properties and crop protection in the tropics, ed. R.Lal and D.J. Greenland, 7-44. Chichester: John Wiley and Sons.

Physical Characteristics of Soils of the Tropics: Determination and Management

R. LAL

1.2.1. INTRODUCTION

Ever-increasing demand for food production has intensified the quest for more production per unit area and for an increase in the area of land under arable cultivation. Some regions of the humid tropics, Latin America and some parts of West and Central Africa, constitute the last great frontier where the opportunity still exists for bringing more land under arable cultivation. In other densely populated areas, efforts have to be made to increase the production per unit area. The role of management of soil physical properties for increasing production per unit area cannot be overemphasized. The development of stable and viable systems of soil management for tropical regions with harsh climatic environments must be based on a thorough understanding of the soil physical conditions, if they are to be successful.

The research information on physical characteristics of the soils of tropical regions in relation to their management is far behind our knowledge of soil chemical and pedological characteristics. Lack of adequately trained personnel is one of the reasons; another is the failure on the part of decision-makers and planners to recognize the importance of soil physical characteristics in maintaining productivity of tropical soils.

An attempt is made in this chapter to review the present state of knowledge of the physical characteristics of soils of various tropical regions. The objective is to discuss the presently available information in terms of developing suitable soil management systems for sustained productivity. One of the difficulties in comparing the results obtained by various researchers is the lack of uniformity in the techniques adopted to characterize soil physical properties. An appraisal of various methods of soil analysis to develop uniform methodology will help reduce the time and effort required to obtain this vital information.

1.2.2. SOIL TEXTURE

Texture refers to the relative proportion of primary particles of sand, silt and clay, and other skeletal material in the soil body. Due to intense rainfall, soils of the humid tropics have been subject to a process of eluviation involving downward movement of clay and other suspended colloids. As a result the surface horizons of these highly leached soils can be of coarse texture, containing little clay and silt. The 'clay bulge' in the subsoil horizon of many soils in the tropics is partly attributed to illuviation and flocculation of suspended colloids in this horizon. Smyth and Montgomery (1962) and Ashaye (1969) in western Nigeria, Ahn (1968) in Ghana, and Sys (1972) and D'Hoore (1968) in Central Africa have all observed the texture of the surface horizon of soils in the wet tropics to be dominantly sandy loam to loamy sand.

Silt:clay ratio is an important criterion for classification of soils in the tropics (Van Wambeke, 1962) and for evaluating phenomena such as clay migration, stage of weathering, and age of parent material (Ashaye, 1969). The soils of the West African region, particularly those derived from the basement complex rocks, have low silt contents. Low silt content, clay migration due to excessive leaching, and the changes in silt:clay ratio with depth in soil profile are common features of soils developed on basement complex rocks (Ashaye, 1969; Lal, 1979). In general, silt:clay ratio is higher in the surface horizons and declines to a constant value at about a metre below the surface (Lal, 1979).

Some upland soils of the West African region are also characterized by a well-defined gravelly horizon at different depths (Collinet, 1969; Leveque, 1969; Riquier, 1969; Segalen, 1969; Smyth and Montgomery, 1962). Similar soils have been reported in the tropics of Latin America (Alexander, 1955; 1973; Santamaria, 1965; Thomas, 1974) and South East Asia (Panabokke and Quirk, 1957; Panton, 1954). These gravel horizons are often compacted and rigid because of the clay matrix, and can cause a mechanical impedance to the root development of various arable crops (Babalola and Lal, 1977a,b). In addition, variations in gravel concentration and size and depth and thickness of the gravel horizon are important reasons for soil variability. The predominance of savanna in regions once covered with lush green tropical forest is also attributed to low water availability and poor root penetration, resulting in lack of forest rejuvenation in these gravelly soils. Some savanna soils in Venezuela are characterized by an abrupt gravelly B2t horizon at 15–30 cm depth (Comerma, 1968).

One theory attributes the development of this well-defined gravel horizon to the intense activity of earthworms and termites. In the savanna region of West and Central Africa, termite mounds both abandoned and active may constitute up to 20 per cent of the land surface. Termite activity can influence the texture of the surface horizon by bringing subsoil material to the surface (e.g. Perez-Escolar and Lugo-Lopez, 1968). Termite activity produces stone-free topsoil and concentrates coarse material and gravel in the subsoil. In addition, other soil physical

characteristics such as bulk density, infiltration rate, and root penetration are also influenced. Termite activity can also influence both the pattern of nutrient distribution and mineral soil horizons (Watson, 1962).

The natural texture (feel) of many tropical soils can be considerably different from that indicated by their particle size distribution. This is attributed to the formation of stable microaggregates of silt and sand size from clay by the action of iron and aluminium oxides (De Vleeschauwer *et al.*, 1979) and other agents such as organic matter content (Perez-Escolar and Lugo-Lopez, 1968). This subject is discussed at some length by Ahn in Chapter 2.3 of this book. The method of mechanical analysis of soil must therefore take into consideration the possible presence of unusually stable sand- and silt-sized aggregates. The soil must be thoroughly dispersed, by adequate chemical and mechanical means, before subjecting it to a routine analytical procedure. The primary particles of sand size should be subdivided at least into coarse and fine sand, if not into all the size fractions proposed in the USDA system of textural classification.

1.2.3. STRUCTURE

The conventional definition of soil structure as 'the arrangement of primary particles into aggregates' is perhaps not broad enough to incorporate all attributes of this important physical characteristic that plays a dominant role in the management of soils in the tropics. Different concepts of soil structure, its management and methods of determination, are explained in Chapters 2.1 and 2.2 by Greenland and Quirk. It must be realized, however, that soil structure and its stability govern soil–water relationships, aeration, crusting, infiltration, permeability, runoff, interflow, root penetration, leaching losses of plant nutrients, and, therefore, the productive potential of a soil. Whereas soil texture cannot be changed, at least over a short period of time, by any economical means, successful management of soils in the tropics as elsewhere depends on the management of soil structure. Soil structure is therefore an important but vaguely defined property. From the point of view of soil management, soil structure may be regarded as 'the property of a soil that regulates a continuous array of various sizes of interconnected pores, and their stability and durability, governs retention and movement of water, regulates gaseous diffusion from and into the atmosphere, and controls root proliferation and development'. It is a complex phenomenon indeed. Soil structure, therefore, both directly and indirectly, promotes or controls phenomena such as wind and water erosion, waterlogging and aeration, drought stress, leaching losses of plant nutrients, soil temperature, trafficability of farm machinery, root penetration and development, and crop yield. Certainly there are diverse opinions on the subject, and there is no single method of determination that can evaluate this complex soil property.

Structural behaviours of soils of different tropical regions have been investigated by many researchers. However, the techniques adopted depend on the

objectives. Whereas stability of structural aggregates to raindrop impact and maintenance of pore space continuity are important criteria for soils prone to erosion by water, air:water permeability ratio and oxygen diffusion rate are suitable assessment methods for soils subject to waterlogging. An assessment of slaking and incipient failure is important for soils susceptible to crust formation, whereas shear strength and resistance to a simulated root (penetrometer) may be monitored to evaluate the physical strength of the soil. The most important criterion, however, that relates to all aspects listed above, is the pore size distribution and its stability.

Various methods employed for structural evaluation are discussed below:

(i) *Rainfall acceptance*

Soil erosion by water being a major problem in the tropics, rainfall acceptability has been considered an important test of soil structure. The ability of a soil surface to accept a continuous heavy rainfall is a critical factor in the prevention of accelerated erosion of soils in the tropics. Earlier work on rainfall acceptance was done in East Africa by Pereira (1955; 1956) and Rose (1960; 1962). Pereira (1955) defined rainfall acceptance as the proportion of the simulated rain transmitted from the surface into the subsurface horizons. Infiltrability of the soil surface is related to the stability of aggregates to raindrop impact and to the resistance to the shearing force of running water. Pereira and his colleagues (Pereira, 1941; 1955; 1956; Pereira and Beckley, 1953; Pereira and Jones, 1954a,b; Pereira *et al.*, 1954; 1958; 1964; 1967; Pereira and Hosegood, 1964) used this criterion to evaluate soil structure under different management systems. For example, Pereira *et al.* (1967) reported that continous cultivation with ploughing and harrowing decreased the rainfall acceptance from 94 per cent in the first year to 75 per cent in the fourth year after initiating cultivation of arable crops. Similarly, the rainfall acceptance of clean weeded plots was only 80 per cent of that of the unweeded plots (Pereira *et al.*, 1964). Fallowing with grasses and leguminous cover crops improved the rainfall acceptance compared with soils under arable crops (Pereira *et al.*, 1954). Fallowing with elephant grass (*Pennisetum* sp.) and *Paspalum* improved rainfall acceptance more than fallowing under legumes such as *Pueraria* (Table 1.2). Similar results from West Africa have been reported by Lal *et al.* (1978) (Figure 1.1). The maximum infiltration rate was

Table 1.2. Effect of grasses and leguminous fallow on rainfall acceptance: adapted from Pereira *et al.* (1954)

Fallow crop	Infiltration rate (cm/hr)	Percolation rate (cm/hr)
Grasses	10.8	37.3
Legumes	9.9	28.9
Arable crops	9.0	24.1
LSD (0.05)	2.6	10.9

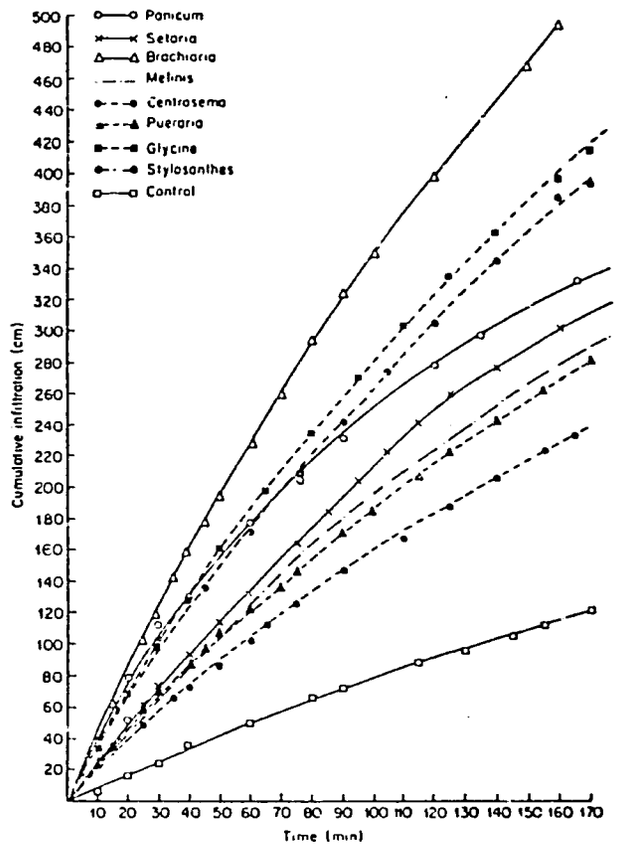


Figure 1.1 Infiltration into Egbeda soil after growth of different vegetative fallows

observed under *Brachiaria*, a grass, although *Glycine*, *Stylosanthes*, and *Pueraria* have the additional advantage of contributing towards soil nitrogen, and an arable crop can be easily planted through them by 'sod seeding'. In loessal savanna soils of northern Nigeria, Wilkinson (1975) observed a significant improvement in the infiltration rate after six years of grass fallow. However, most of the benefits of im-

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provement of the infiltration rate with fallow disappeared with the first moldboard ploughing prior to establishing arable crops. The maintenance of soil structure, by a grass or leguminous fallow, should be an important criterion in developing suitable tillage systems.

Dagg and Macartney (1968) adopted a different approach to moisture conservation. Rather than improving rainfall acceptance, they developed a tillage system that prolonged the time for water to infiltrate into the soil. Water retention in the surface was improved by a system of 'tied ridges'. This system did not prove economical and effective in sandy soils of northern Nigeria (Kowal, 1968; 1969) in spite of the authors' limited success in water conservation reported in earlier investigations (Lawes, 1962).

(ii) *Aggregate stability*

Rainfall acceptance is related to aggregate stability, and has been used by various researchers to evaluate soil structure. Stability of soil aggregates is determined by a process of sieving in water with and without previous treatment. In East Africa, wet sieving without treatment was used by Martin (1944a,b), Pereira (Pereira and Jones, 1954b), and Rose (1962). Pereira and Jones (1954b) reported that water-stable aggregates greater than 0.5 mm were 7 9, 30.8, and 31.2 per cent of the total soil volume in clean weeded, slash weeded, and unweeded soil. Structural stability declined with cultivation. Cultivation produced massive clods that adversely affected crop yields (Taylor, 1974). Martin (1944a) reported from 10 years' work in Uganda that the percentage of water-stable aggregates >0.5 mm was 30.5 under cultivation compared with 52.9 under grass cover (Table 1.3).

Table 1.3. Effect of grass fallow and cultivation on water-stable aggregates (>0.5 mm) in a Ugandan soil: after Martin (1944a)

Treatment	Per cent water-stable aggregates	Treatment	Per cent water-stable aggregates
2 years grass fallow + 1 year cotton	48.2	4.5 years cultivation	35.6
3 years grass fallow	57.1	3.5 years cultivation, 2 years fallow	36.9
4 years grass fallow	63.1	2 years cultivation, 3 years fallow	42.0
3 years natural bush fallow	56.2		
LSD (0.05)	8.5		

While investigating the structure of tropical red and black earths from Hawaii, Ahmad *et al.* (1969) observed a significant effect of the cations on the exchange

complex on its stability. The percentage of stable aggregates and saturated conductivity were also related (Table 1.4). The aggregate stability was in the order of Ca = Mg > K ⩾ Na.

Table 1.4. Effect of cations on structural stability and saturated hydraulic conductivity of tropical soils from Hawaii (Ahmad *et al.*, 1969)

Cation	Plastic limit (%)	Stable aggregates (%)	Saturated hydraulic conductivity (cm/hr)
(a) *Tropical black earth*			
Ca	30	12.1	0.10
Mg	27	9.5	0.14
Na	27	0.0	0.00
K	28	2.8	0.00
Untreated control	30	85.8	0.17
(b) *Tropical red earth*			
Ca	40	62.6	0.26
Mg	45	67.8	0.13
Na	45	0.0	0.00
K	48	25.2	0.00
Untreated control	43	14.9	0.13

Considerable work on structural stability has been done on soils of Puerto Rico by Lugo–Lopez and his colleagues (Lugo–Lopez, 1969; Lugo–Lopez *et al*; 1957; Lugo–Lopez and Juarez, 1959; Lugo–Lopez and Escolar, 1959; 1969), and in Hawaii by Uehara (Sharma and Uehara, 1966; 1968; Uehara *et al.*, 1962; 1972). Bonnet and Lugo–Lopez (1950) related stability of aggregates of an upland catalina clay soil to its dispersion ratio, erosion ratio, and to soil erosion. Aggregate stability was not correlated with clay or silt content, but with soil organic matter content (Table 1.5).

Table 1.5. Relation between stability of soil aggregates of a vertisol, from Laja Valley in Puerto Rico, and soil components: Lugo Lopez and Juarez (1959)

Soil component	*F* value	*r*
Clay	0.75	0.08
Clay + silt	0.80	0.11
Clay + silt + organic matter	29.78**	0.66
Clay + silt + organic matter + Ca + Mg	28.48**	0.70
Clay + silt + organic matter + Ca + Ma + Na	29.31**	0.74

Soil organic matter therefore plays an important role in structural stabilization, more perhaps through an increase in cohesion of aggregates than with a decrease

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in their wettability (Godefroy and Jacquin, 1975, Panabokke and Quirk, 1957). The effect of planted fallow on the structural stability of an Oxisol (Terra Roxa) and an Ultisol (Red Yellow Latosol) in Brazil was similar to that observed in East Africa (Grohmann and Conagin, 1960). Cultivation decreased the stability of aggregates by 69 per cent in an Oxisol and 10 per cent in an Ultisol compared with grass fallow. Research on the structural stability of Hawaiian soils has elaborated on the effect of mineralogical characteristics, including that of sesquioxides and allophanes (Caguan and Uehara, 1965; Uehara *et al.*, 1962; 1972) on soil moisture retention (Sharma and Uehara, 1966; 1968). More recent work on soil erodibility under simulated rainfall is discussed in another section of this chapter (Dangler *et al.*, 1976).

In francophone West Africa various researchers have compared stability of aggregates to wet sieving after pretreatment with organic liquids (Chevalier, 1949; Dabin, 1962b; Hénin *et al.*, 1958; Monnier, 1965). The coefficient of stability S is expressed by:

$$S = (A + L)/(Ag_{aq} + Ag_{alcohol} + Ag_{benzene}) \qquad (1.1)$$

where $A + L$ is the percentage of silt and clay and Ag_{aq}, $Ag_{alcohol}$ and $Ag_{benzene}$ refer to the percentages of aggregates from wet sieving without pretreatment and with pretreatment with alcohol and benzene respectively. The index S refers to instability rather than the stability of soil aggregates, and ranges from 0.1 for a stable to 100 for an unstable soil. Hénin's index of structural stability applied to a range of West African soils under cultivation (Inceptisols, Ultisols, and Oxisols) was evaluated by Boyer and Combeau (1960) and Boyer (1970).

Combeau and Monnier (1961) used another index to determine structural stability. This index was based on aggregate size and is

$$S = \frac{(\text{Clay + silt})\ \%}{\text{Mean per cent aggregates}} \qquad (1.2)$$

'Mean per cent aggregates' was calculated by wet sieving and determining the weight of all aggregates greater than 200 μm minus 0.9 × (wt. of coarse sand).

(iii) *Soil erodibility, detachability, and transportability*

With the development of the so-called 'Universal soil loss equation' that facilitated soil erosion prediction, various researchers have obtained direct or indirect measurements of soil erodibility (K). The term soil erodibility encompasses detachability, i.e. the ability of aggregates to withstand raindrop impact (structural stability as described in the previous section), and transportability as related to the carrying capacity of water. Soil detachability has been measured in terms of the kinetic energy required to break a natural soil clod, and is a function of clay mineralogy, texture, organic matter content, and heat of wetting (Bruce-Okine and Lal, 1975). Pre-equilibration of soil samples at a relative humidity of 98 per cent (pF 4.2) is necessary to minimize the effects of the initial soil moisture content and the heat of wetting. A comparison of various detachability indices for a range of soils from Nigeria has been recently reported by De Vleeschauwer *et al.* (1979). After considering the relative merits of all indices, the choice was narrowed down to either the De Leenheer-De Boodt index (De Leenheer and De Boodt, 1959) or Hénin's stability index (Hénin *et al.*, 1958), both of which were related to detachability. The multiple correlation coefficient relating soil erosion determined by a laboratory rainfall simulator and the detachability index of De Leenheer and De Boodt was significantly correlated only with soil organic matter content and CEC (Table 1.6). The relative proportion of water-stable aggregates was related to pF ratio and organic matter content.

Table 1.6. Relation of multiple correlation coefficient (R^2) of soil loss (SL), De Leenheer–De Boodt (LD) index, and water stable aggregates (WS) to soil properties: after De Vleeschauwer *et al.* (1979)

Soil properties	Detachability indices		
	SL	LD	WS
% clay + pF ratio	0.19	0.15	0.25
% clay + % organic carbon (O.C.)	0.09	0.32	0.21
% clay + CEC	0.40	0.25	0.07
% clay + % aggregates >2 mm	0.13	0.14	0.09
pF ratio + % O.C.	0.30	0.28	0.51*
pF ratio + CEC	0.43	0.17	0.25
pF ratio + % aggregates > 2 mm	0.19	0.05	0.29
% O.C. + CEC	0.83**	0.78**	0.47
% O.C. + % aggregates >2 mm	0.29	0.36	0.40
CEC + % aggregates >2 mm	0.39	0.15	0.09

Bonnet and Lugo-Lopez (1950) reported that an upland Catalina clay profile in Puerto Rico, with a dispersion ratio of 12–20, colloid/moisture equivalent ratio of 0.97–2.26, and erosion ratio of 6–14, lost from 5.3 to 7.1 tonnes of soil per 2.5 cm of runoff per ha per year. Based on these preliminary findings, Lugo-Lopez (1969) predicted the erosiveness of some soils from Puerto Rico by an index that involved dispersion ratio and soil moisture equivalent (Equation 1.3).

$$\text{Erosion ratio} = \frac{\text{Dispersion ratio}}{(\text{Colloid content/moisture equivalent})} \qquad (1.3)$$

He observed that erosion ratio (Y) was linearly related to per cent of silt and clay aggregated (Equation 1.4).

$$Y = 125.5 - 1.42\ (\text{per cent silt and clay aggregates})$$

Laboratory and field rainfall simulators have been widely used to obtain quick

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estimates of 'soil erodibility'. However, at best the results obtained by these methods reflect the relative erodibility of a soil. Rose (1960) obtained relative erodibility values for some East African soils using a laboratory simulator. Similar studies have been conducted in West Africa by Roose (1973) and Aina *et al.* (1978), in Hawaii by Dangler *et al.* (1976), and in Brazil by Mondardo (Mondardo and Vieira, 1975) and Wunsche (1977). The relative erodibility of Alfisols, Vertisols, and Inceptisols from Nigeria as investigated by a laboratory rainfall simulator is shown in Table 1.7. Without proper adjustment, these values cannot be used in the universal soil loss equation for predictive purposes.

Table 1.7. Relative erodibility index for some Nigerian soils: Aina *et al.*, (1978)

Soil type	Relative erodibility index on a 5 per cent slope	
	Wet run	Dry run
Typic Chromustert (Ngala)	0.43	0.77
Oxic Paleustalf (Funtua)	0.09	0.57
Oxic Paleustalf (Dangappe)	0.07	0.37
Typic Ustorthent (Aponiu)	0.08	0.16
Oxic Paleustalf (Egbeda)	0.06	0.28
Typic Paleudult (Onne)	0.001	0.001
Oxic Paleustalf (Itagunmodi)	0.001	0.001
Oxic Paleustalf (Alagba)	0.001	0.001
Orthoxic Tropholumult (Ikom)	0.001	0.001
LSD (0.05)	0.02	0.15

(iv) *Porosity and pore size distribution*

Total porosity and apparent bulk density has often been used to assess soil structure. A knowledge of apparent density can be used to reduce the variation in the physical evaluation of a range of soils (Forsythe and Diaz-Romeo, 1969). Methodology for characterization of pore space is described in Chapter 2.1 by Greenland. Pereira and his colleagues (Pereira and Jones, 1954b; Pereira *et al.*, 1964) related soil management techniques to total porosity, and to relative proportions of macropores determined by drainage at 50 cm suction. Whereas rainfall acceptance was not related to total pore space, the percolation and infiltration rates were related to macroporosity (Pereira and Jones, 1954b). For example, the relative proportion of freely drainable (transmission) pores was 20, 23, and 24.4 per cent, with corresponding percolation rates of 24.9, 26.2, and 39.6 cm/hr for clean weeding, slash weeding, and unweeded plots respectively (Pereira and Jones, 1954b). Pore size distribution in relation to available water and root growth in some soils of Nigeria has been reported by Kowal (1968) and Babalola and Lal (1977b).

Some tropical soils are naturally compacted and have low total porosity (Bridge *et al.*, 1975; Honisch, 1974; Marino, 1965; Parthasarthy *et al.*, 1976); others are easily compacted by methods of forest removal (Cunningham, 1963; Lal and Cummings, 1979) and by soil mismanagement (Casagrande *et al.*, 1975; Shukla, 1974).

Porosity and pore size distribution of soils in Latin America have been investigated by many researchers (Roberts, 1933; Smith and Cernuda, 1952) and have been related to soil water movement (Lugo-Lopez and Escolar, 1959) and to root growth (Lugo-Lopez, 1960). Grohmann (1960a) monitored pore size distribution of a range of Brazilian soils and reported that the relative proportion of fine pores was high in Red Latosols (Ultisols), Terra Roxa (Oxisol), and a red Yellow Podzolic soil derived from sandstone (Ultisol). As much as 40 to 77 per cent of pores were >0.02 mm in diameter. Medina and Grohmann (1966) observed that micropores represent 60 to 70 per cent of total pore space in a Latosol Roxa. Similar to the East African experience, it was observed that the total porosity of some Brazilian soils declined with cultivation (Oliveira, 1967), and root penetration in the Barrieras series in the Tabuliera area of Brazil was seriously impeded as a result of a plough pan formed by cultivation. Similar observations were made in the Recife series (Oliveira *et al.*, 1968). Excessive and unnecessary cultivation, overgrazing, and overstocking can also degrade soil structure. For example, Chandler *et al.* (1964) reported a decrease in macroporosity to 7 to 9 per cent of total pore volume as a result of overgrazing of pastures in Catalina clayey soil (Typic Haplorthox) of Puerto Rico.

1.2.4. WATER MOVEMENT

Soil structure, particularly pore size distribution and continuity, is related to water transmission and hydrological characteristics. In fact, the criterion for characterization of soil structure used by Pereira in East Africa was related to percolation and infiltration rates. The ability of a soil to transmit water at a rate comparable to that of rainfall intensity is an important soil property that maintains adequate soil-water balance and controls or accelerates runoff and erosion.

(i) *Infiltration*

In general, the water-intake rate of tropical soils under their natural vegetation cover is high (Lal, 1976; Lal and Cummings, 1979; Wilkinson, 1975; Wilkinson and Aina, 1976). However, the removal of vegetation and introduction of mechanized tillage operations result in disturbance and exposure of soil and cause a rapid decline in the infiltration rate (Cunningham, 1963; Lal and Cummings, 1979).

The infiltration rates of various soils of Puerto Rico have been extensively studied by Bonnet and Lugo-Lopez (1952) and Lugo-Lopez *et al.* (1968) (Table

1.8). The mulch of sugarcane trash in the Vega Alta silt clay at Rio Piedras, Puerto Rico, increased the infiltration rate by 30 per cent compared with the practice of burning trash. Wolf and Drosdoff (1976) reported the results of infiltration studies on two clayey Oxisols, two clayey Ultisols, and a sandy Oxisol from Puerto

Table 1.8. Eight-hour infiltration rate of different soils in Puerto Rico: after Lugo-Lopez *et al.*, (1968)

Soil group	Eight-hour infiltration rate Minimum (cm/hr)	Maximum (cm/hr)
Vertisols	0.18	9.58
Entisols	2.32	27.55
Inceptisols	2.75	13.25
Alfisols	2.78	11.58
Mollisols	8.22	19.55
Oxisols	8.45	15.40
Ultisols	7.40	23.68

Rico. Water infiltration into all soils was very rapid, reaching a rate of 9 cm/hr after one hour of continuous flooding. High structural stability of the clayey soils permitted infiltration rates in excess of that for the sandy soil. Water-intake rates for some soils of Hawaii have been reported by Uehara *et al.* (1972) and for some of Surinam by Kamerling (1975).

Gavande and Gonzalez (1969) reported the infiltration rate of four soil series in the Alajuela region of Costa Rica. Both the average and instantaneous infiltration rate were exponentially (negative exponent) related to the time (7). The numerical value of the exponent was different for different soil series and ranged from −0.02 to −0.17 for the average infiltration rate, and from −0.02 to −0.95 for the instantaneous equilibrium rate.

Infiltration rates of Nigerian soils have been studied by Wilkinson (1975), Wilkinson and Aina (1976), and Lal *et al.* (Lal *et al.*, 1978; Lal and Cummings, 1979). Studies conducted on an Alfisol in western Nigeria indicated that the infiltration rate of an eroded soil was considerably improved by fallowing with grass and leguminous cover crops (unpublished data of Lal). However, the improvement was rather slow and the soil did not attain the infiltration rate that existed prior to clearing even after three years of continuous fallowing. One of the important reasons for high infiltration rates in soils in western Nigeria is the abundant activity of the earthworm *Hyperiodrilus africanus*, which produces turret like casts 2 to 8 cm long, and also of *Eudrilus eugeniae*, that produces 1 mm spherical casts. The intense activity of earthworms and other soil animals produces continuous and stable channels giving the soil a honeycomb like structure. Badly

eroded and structurally degraded plots are devoid of these worms. Unless artificially inoculated, worm activity does not redevelop under cover crops, at least not for several years.

High infiltration rates, determined by double-ring infiltrometers, can be partly attributed to lateral flow. Biotic activity in the surface horizon influences the horizontal infiltration rate. The horizontal component of the saturated hydraulic conductivity of these soils (K_r) is at least as much in magnitude as the vertical component (K_v). This is obvious from the results shown in Figure 1.2. Compared

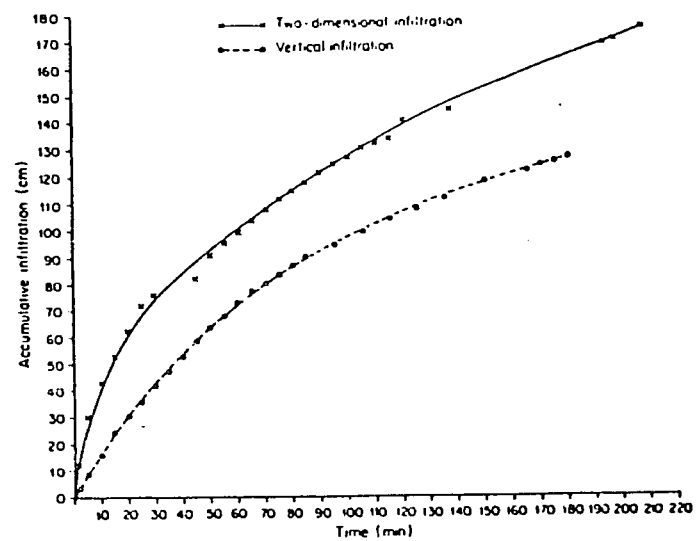

Figure 1.2 Vertical and two-dimensional infiltration for an Egheda soil series

with one-dimensional (vertical) flow, at least 40 cm of water was absorbed by the horizontal flow in a period of three hours. High infiltration rates in Puerto Rican soils reported by Wolf and Drosdoff (1976) were also attributed to lateral movement, downslope. This lateral movement was also responsible for downslope movement of NO_3–N. Because of the high infiltration rate, Avella and Rodriguez (1973) recommended in-furrow methods for determining the infiltration rates of some Colombian soils. This type of infiltration test is useful for planning irrigation programmes (Borden *et al.*, 1974). Similar observations have been reported for

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soils of north-eastern Thailand by Bridge *et al.* (1975) and for some soils in western Nigeria by Wilkinson and Aina (1976).

(ii) *Hydraulic conductivity*

The equilibrium infiltration rate is closely related to saturated hydraulic conductivity. The information on saturated and unsaturated hydraulic conductivity of tropical soils is rather scanty. One of the difficulties is the lack of suitable methodology for determining the hydraulic conductivity of highly variable soils, particularly those with high concentrations of gravel.

The saturated hydraulic conductivity of some soils from Hawaii could be related to aggregate stability (Ahmed *et al.*, 1969; Sharma and Uehara, 1968) and to the nature of cations on the exchange complex (Ahmed *et al.*, 1969) (Table 1.4). Gumbs (1974) reported that mean laboratory measured values for some soils in Trinidad were usually greater, by a factor of 1.5 to 15 times, than the field values. The saturated hydraulic conductivity was highly variable, but significantly correlated with coarse sand (positive) and fine sand and silt (negative). Bridge *et al.* (1975) observed similar trends in hydraulic conductivity values measured in the laboratory and those obtained from infiltration rates measured in the field. The hydraulic conductivities of the surface horizons of four soil series in Thailand, the Phetchaburi, Nakhon Pathon, Chai Nat, and Ratchaburi series, were 81.8, 23.1, 34.4, and 4.4 cm/day respectively, compared with 3.2, 34.1, 0.47, and 48.6 cm/day for the layers immediately beneath. The unsaturated hydraulic conductivity (K_θ) decreased by at least three orders of magnitude as suction increased from 0 to 100 cm of water.

A little information is available on the hydrological characteristics of soils of the West African region. Humbel (1975) compared the results of a model study on water movement with that of direct measurement of permeability on a ferralitic soil in the Cameroun. Mensah-Bonsu and Lal (1975) compared the saturated

Table 1.9. Comparison between the field and laboratory determined and calculated saturated hydraulic conductivity of an Alfisol: Mensah-Bonsu and Lal (1975)

Profile	Depth (cm)	Laboratory (cm/sec)	*In situ* (cm/sec)	Calculated (cm/sec)
1	0–15	0.061	0.0025	0.0116
	15–30	0.066	0.0018	0.0134
	30–68	0.019	0.0005	0.0141
	68–115	0.00048	0.000022	—
2	0–15	0.017	0.0017	0.015
	15–33	0.034	0.0014	0.0097
	33–93	0.0055	0.0032	0.0062
	93–135	0.0044	0.0031	0.0096

hydraulic conductivity of an Alfisol determined in the laboratory from undisturbed cores with that of *in-situ* measurements and with those calculated on the basis of an empirical model based on particle size distribution. Assuming the *in-situ* measured values to be the most representative of field behaviour, laboratory determined values of hydraulic conductivity even on undisturbed cores were higher than the *in-situ* determined values by 24 to 40 times (Table 1.9).

The saturated hydraulic conductivity of soil, as far as possible, should be determined *in-situ*. The soil volume of undisturbed cores is too small, considering the high variability of soils in the tropics, to represent adequately the soil mass.

1.2.5. SOIL WATER RETENTION AND SOIL MOISTURE CONSTANTS

Soil structure (pore size distribution and size, shape, and arrangement of aggregates) also influences water retention. Soil moisture retention characteristics should be determined on undisturbed cores or *in-situ*.

(1) *Moisture retention curves*

Relationships between soil moisture suction and moisture retention (pF) for tropical soils have been studied by several workers. It has been generally concluded that the pF curves determined *in situ* can be significantly different from those determined on undisturbed cores. For example, data in Figure 1.3 indicate significant differences in pF curves of an Alfisol determined *in situ* compared with those determined in the laboratory on undisturbed cores. In general, core samples retained less water at a given suction compared with *in-situ* measurements. Similar results have been reported for Chilean soils by Millar (1973)

Moisture retention characteristics were found to be significantly influenced by clay mineralogy (Borden *et al.*, 1974; Warkentin, 1974). The nature of cations on the exchange complex also influences moisture retention (El-Swaify *et al.*, 1970; Lognathan and Krishnamoorthy, 1976; Moss, 1964). El-Swaify *et al.* (1970) observed that moisture retention at different suctions of a tropical red earth consisting predominantly of kaolin and iron oxides was independent of the nature of the saturating cation. However, the moisture retention values of a tropical black earth consisting predominantly of montmorillonite were dependent upon the nature of the saturating cations, with Na giving the highest value and K the lowest.

The moisture retention of predominantly coarse-textured soils with kaolin and iron oxide clay minerals is generally low. The behaviour of Vertisols with montmorillonite, and the soils derived from volcanic ash materials and rich in allophanes (Andepts) is quite different. An example of the latter is shown in data for soils from Costa Rica (Gonzalez and Gavande, 1969).

These soils have exceptionally high water retention capacity and a low bulk

density. Soils of organic origin, i.e. Histosols, also have high moisture retention capacities (Perez-Escolar *et al.*, 1974).

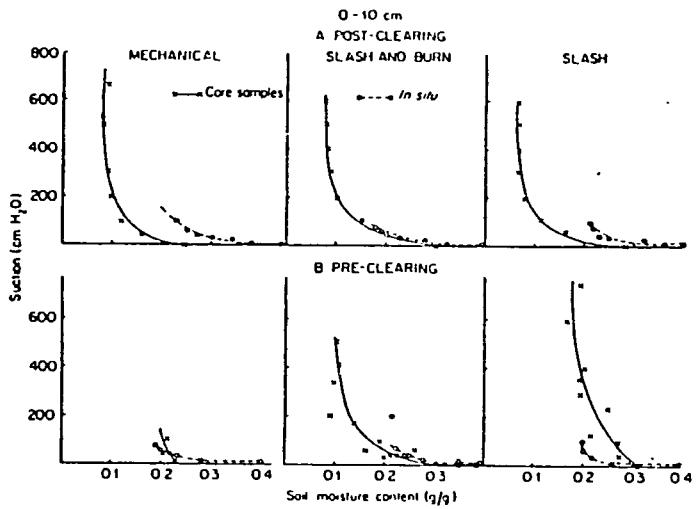

Figure 1.3 Soil moisture characteristics as affected by methods of clearing and determination

Similarly, a complete range of moisture characteristics of eight lateritic and alluvial soils from the Amazon region in the north-east of the State of Maranho, Brazil, has been described by Roeder and Bornemisza (1968). The moisture retentions for these soils were similar to those of an Alfisol (Figure 1.3). The moisture retention ranged from 20 to 25 per cent at 0.3 bar and 6 to 8 per cent at 12 bar suction.

The preparation of soil samples, such as air-drying of soil prior to pF determination in the laboratory, can have a significant effect on moisture characteristics. Forsythe *et al.* (1969) reported that volcanic ash soils in the humid tropics lose their water-holding capacity when air-dried. Similar results were reported by Colmet-Daage and Cucalon (1967).

(11) *Field capacity*

Field capacity, in a dynamic sense, is not a constant value but represents the range of moisture contents retained in the soil when macropores have been

drained against the gravitational pull. Though conventionally field capacity has been estimated in the United States to be equivalent to soil moisture retention when a saturated soil is subject to a suction of 1/3 bar, 1/10 bar and lower suctions have been found appropriate in other parts of the world. Wolf and Drosdoff (1976) reported for some Puerto Rican soils that the field capacity was established at 1/15 to 1/20 bar. The field capacities of some Ugandan soils have been estimated to be at 0.1 bar suction (Pidgeon, 1972). However, Fernandez and Sykes (1968) estimated the field capacity of some Brazilian soils at 1/3 bar suction, and reported that the moisture equivalent was not similar to the moisture retained at 0.3 bar suction. Similarly, Medina and Grohmann (1966) estimated field capacity at 0.3 bar suction. *In-situ* measured field capacity values are generally at suctions lower than 0.3 bar, and are more reliable (Avella and Rodriguez, 1973).

Many researchers have estimated field capacity from soil components such as texture and organic matter content (Table 1.10). Though estimates can be obtained by this empirical method, the reliability of these results is questionable. Lugo-Lopez (1951) reported functional relationships between moisture retention at several equilibrium points and the clay content of some Puerto Rican soils and concluded that the field capacity of both lateritic and non-lateritic soils can be estimated from their clay contents. Pidgeon (1972) observed significant correlations between particle size composition and field capacity of some soils in Uganda. Similar correlations for selected soils from Zaire were found by Tran-Vinh An and Nguba (1971), who reported that 80 to 86 per cent of the variation in water content at field capacity was directly related to contents of clay, silt, and organic matter. The moisture retention in some Costa Rican Latosols, Andosols, and Inceptisols was found to be significantly correlated with clay silt, fine sand, and organic matter content (Gavande, 1968; Gonzalez and Gavande, 1969).

(iii) *Wilting point*

Wilting point refers to the range of moisture contents at which the rate of water supply to roots lags behind the evaporative demand of the atmosphere. This implies that wilting point is not a constant property but varies with crop and the evaporative demand of the atmosphere. The numerical value of the unsaturated hydraulic conductivity (K_θ) is an important factor affecting the wilting point of a soil. Conventionally, wilting point is estimated to be equal to the moisture content retained when saturated soil is subjected to a suction of 15 bars. However, many soils of the tropics with coarse textures do not exhibit significant differences in moisture retention between 1 or 2 bar suction and 15 bar suction. For these soils wilting often occurs at suctions much lower than 15 bars. This, however, depends on soil texture and mineralogical composition, as explained in the following examples.

Lugo-Lopez and his associates (Lugo-Lopez, 1952a,b; Perez-Escolar and

Table 1.10. Relationships of field capacity, wilting point, and available water to soil components

Region	Regression equation	R^2	Source
(a) *Field capacity*			
Puerto Rico (lateritic soil)	$Y = 10.02 + 1.65\,(\text{clay}) - 0.02\,(\text{clay})^2$	0.91**	Lugo-Lopez (1951)
Puerto Rico (non-lateritic soil)	$Y = 10.98 + 1.70\,(\text{clay}) - 0.022\,(\text{clay})^2$	0.92**	Lugo-Lopez (1951)
Uganda	$Y = 7.38 + 0.16\,(\text{silt}) + 0.30\,(\text{clay}) + 1.50(\text{O.M.})$	0.96**	Pidgeon (1972)
Nigeria	$Y = 0.102 + 0.003\,(\text{clay})$	0.84**	Lal (1979b)
Zaire	$Y = 3.22 + 0.31\,(\text{clay}) + 0.35\,(\text{silt}) + 5.61(\text{O.M.})$	0.80**	Tran-Vinh-An and Nguba (1971)
Sudan	$Y = 19.6 + 0.40\,(\text{clay})$	—	Drover (1966)
(b) *Wilting point*			
Puerto Rico (lateritic soil)	$Y = 5.80 + 0.53\,(\text{clay})$	0.89**	Lugo-Lopez (1951)
Puerto Rico (non-lateritic soil)	$Y = 3.28 + 0.53\,(\text{clay})$	0.87**	Lugo-Lopez (1951)
Uganda	$Y = 4.19 + 0.19\,(\text{silt}) + 0.39\,(\text{clay}) + 0.9(\text{O.M.})$	0.99**	Pidgeon (1972)
Nigeria	$Y = 0.003\,(\text{clay}) + 0.006$	0.90**	Lal (1979b)
Zaire	$Y = 0.25 + 0.32\,(\text{clay}) + 0.196\,(\text{silt}) + 2.0(\text{O.M.})$	0.87**	Tran-Vinh-An and Nguba (1971)
Sudan	$Y = 10.53 + 0.22\,(\text{clay})$	—	Drover (1966)
(c) *Available water*			
Uganda	$Y = 169.3 - 1.50\,(\text{clay}) + 6.09\,(\text{O.M.})$	0.89*	Pidgeon (1972)
Surinam	$Y = 0.04\,(\text{clay}) + 0.96\,(\text{silt}) + 3.4(\text{O.M.})$	0.78*	Schroo (1976)
Surinam	$Y = 2.10\,(\text{silt}) + 3.3\,(\text{O.M.}) + 3.2$	0.79*	Schroo (1976)

O.M. = Organic matter. All soil constitutents are expressed as per cent on weight basis.

Lugo-Lopez, 1969) compared the relative values of moisture retention by estimating wilting point by different methods and found that in the case of Catalina clay (Tropactic clayey, oxidic, isohyperthermic Oxisol) with 18.2 per cent iron oxide and high clay content, the wilting point was better estimated at 15 bar suction. There was a significant effect of aggregate size on wilting point. The moisture retentions at 15 bar suction were 25.7, 24.8, and 23.0 per cent for aggregate sizes of 5 mm, 3–5 mm, 2–3 mm, and 1–2 mm respectively. Similarly, Oliveira *et al.* (1966) compared the moisture retention at 15 bar suction with that obtained using the biotic method and found a good agreement between them. Obi (1974) has claimed that okra and sunflower were able to extract water from soils of southern Nigeria (Itagunmodi, Apomu, Iwo, and Oba series) at suctions of 17 bar. The permanent wilting point as observed by the biotic method was then related to the moisture retention curves obtained on disturbed samples as shown in Equations 1.5 and 1.6. The results of this study are shown in Table 1.11.

$$\text{Wilting point with sunflower} = 0.47 + 0.86\,(\text{15 bar moisture \%}) \quad (1.5)$$

$$\text{Wilting point with okra} = 0.61 + 0.63\,(\text{15 bar moisture \%}) \quad (1.6)$$

Sykes (1969) found a wide variation in permanent wilting point. He used a range of soils of different textures and compared the permanent wilting point obtained using five crop species with moisture retention at different suctions. He observed that the wilting point ranged from approximately 7 bars for *Helianthus annus* to 39 bars for *Agropyron intermedium*. The wilting point varied with soil, species, growth environment, and above all the unsaturated hydraulic conductivity of the soil.

Table 1.11. Comparison of wilting point for some Nigerian soils (Obi, 1974)

Soil series	Depth (cm)	Moisture retention at different suctions: Field capacity	15 bar	Wilting, sunflower	Wilting, okra
Itagunmodi	0–25	21.4	13.0	11.6	9.5
Apomu	0–25	16.0	7.2	7.1	3.3
Iwo	0–15	18.0	9.3	8.4	4.9
Oba	0–15	13.6	6.5	5.7	3.4

Some sandy soils in Botswana have been reported to have a very low moisture content of 2.5 per cent at wilting point (Whiteman, 1975). The moisture content at wilting point has also been observed to be related to particles less than 10 μm (Babalola, 1972) and to finer fractions (Rajamanmar and VenKataraman, 1976).

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(iv) *Available soil moisture*

The available moisture capacity of highly weathered coarse-textured soils of the humid tropics is generally low. This is one of the reasons for the frequent drought stress experienced by shallow-rooted arable crops even a few days after a heavy rain. Data in Table 1.12 show that the available water holding capacity of some

Table 1.12. Available water capacity of some Nigerian soils

Location	Soil series	Horizon (cm)	Organic C(%)	Available water capacity (cm/50 cm) Uncorrected	Corrected*
Ibadan	Egbeda (Tropudalf)	0–15	1.50	1.57	1.34
		15–22	0.76	0.89	0.52
		22–50	0.28	2.59	1.08
Ibadan	Ibadan	0–25	1.30	4.12	3.74
		25–50	0.44	2.50	1.40
Ibadan	Iwo	0–16	[illegible]	1.12	0.97
		15–28	1.66	0.98	0.60
		28–45	0.49	1.63	0.96
Ibadan	(Apomu)	0–9	2.48	0.67	0.65
	(Quartzipsamment)	9–36	0.30	1.69	1.64
Ogbomosho	Alagba (Udox)	0–13	1.10	0.68	0.68
		13–36	0.70	1.66	1.66
Nsukka	Nkopologu	0–43	1.23	5.55	5.49
Enugu	Ezilo	0–12	0.86	3.39	3.35
		12–28	0.29	4.81	4.67
		28–50	0.33	6.12	5.83
Benin	Mifor (Udox)	0–35	1.2	0.91	0.91
		35–74	0.7	1.11	1.11

* Corrected for stone concentration in the horizon.

western and southern Nigerian soils is rather low. In the top 30 cm there is enough water for only 5 to 7 days for maize and 3 to 5 days for rice. The low available water holding capacity of soils of various regions of the tropics has also been reported by other researchers (de Melo, 1974; da Silva *et al.*, 1975; Wahab *et al.*, 1976a,b).

The controversy as to whether the water is equally available at various suctions ranging from field capacity to wilting point also exists for soils of tropical regions. The majority of researchers believe that most of the available water is held at relatively low suctions. Gavande (1968) observed that most pores drained between 1/10 and 1 bar suction. Another study by the same author on other, different, soils of Costa Rica indicated high water retention between 0.30 and 0.80 bar suction, followed by an abrupt drop in moisture retention above suctions of 1.0 to 1.2 bars (Gavande and Gonzalez, 1969). The available moisture content of

some Zambian soils has been estimated by Honisch (1974). He concluded that 1/3 to 1/2 of the available water was retained at a suction of less than 1 bar. Similarly, Wolf and Drosdoff (1976) reported that for the soil series of Bayamon, Humata, Torres, and Catalina in Puerto Rico, the bulk of water was released at a tension of less than 1 bar for Oxisols and slightly above 1 bar for Ultisols. Similar observations were made in earlier investigations of Lugo Lopez (1952a) and Smith and Cernuda (1952). The available water retention capacity of some soils of Surinam was calculated from the difference of moisture retained at pF 2 and pF 4.2 (van der Weert and Lenslink, 1974).

The functional relationships between textural components and soil organic matter content with moisture retention at 0, 0.1, 0.3, and 15 bar suctions, and with the difference in moisture retention between 0.1 and 15 bar suctions, for the surface horizons of 11 toposequences from South and western Nigeria are shown in Figures 1.4–1.7.

The available water holding capacity may also be related to organic matter, clay content, to the nature of clay minerals, and parent material.

(v) *Estimation of soil moisture regime*

One objective of determining soil moisture characteristics and hydrological properties is to compute the water balance of a region. The information on water balance helps plan cropping patterns, supplementary irrigation requirements, and special precautionary measures needed to manage surplus water. A simple water balance can be made by computing the water deficit as the difference between potential evapotranspiration and the precipitation received in that period. Such a water balance has been computed for Brazil by de Camargo (1962) and for Venezuela by Burgas (1965).

Another approach would be to determine, in detail, different components of the hydrological cycle including runoff, deep percolation, evapotranspiration, and soil water storage. Detailed work on this type of water balance has been reported from East Africa by EAAFRO, in Northern Nigeria by Lawes (1962) and Kowal (1968; 1969), in the Ivory Coast by Roose (1973), in Senegal by Dancette (1971), and in Sao Paulo, Brazil, by de Camargo (1962). Indirect estimates of soil water characteristics have been obtained from empirical relations involving information on bulk density, true density, and textural composition (Casimiro, 1971).

Evapotranspiration has been computed by using Thornthwaite's method for some locations in Costa Rica, and predictions made for soil moisture storage using both actual and potential evapotranspiration (Garcia Benavides and Legarda, 1974). This work was extended by Forsythe (1976), who developed an empirical relationship for predicting soil moisture storage from weather records. He assumed that the ratio of evapotranspiration to potential evapotranspiration decreased linearly with decreasing extractable soil moisture.

Direct measurements of soil moisture storage by neutron moisture meter have

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been made by various researchers. Dancette (1971) monitored soil water storage in sandy soils of Senegal, and the technique has been employed in Nigeria for determining the water extraction pattern of maize in lysimeters by Babalola and Lal (1974), and in perennial crops by Atago (1973). Water balance under tea in Kenya has been investigated by Cooper (1974). Charoy (1974) observed that *in-situ* soil moisture characteristics in Niger could be better measured using the neutron moisture meter, and chapters in this volume describe similar studies.

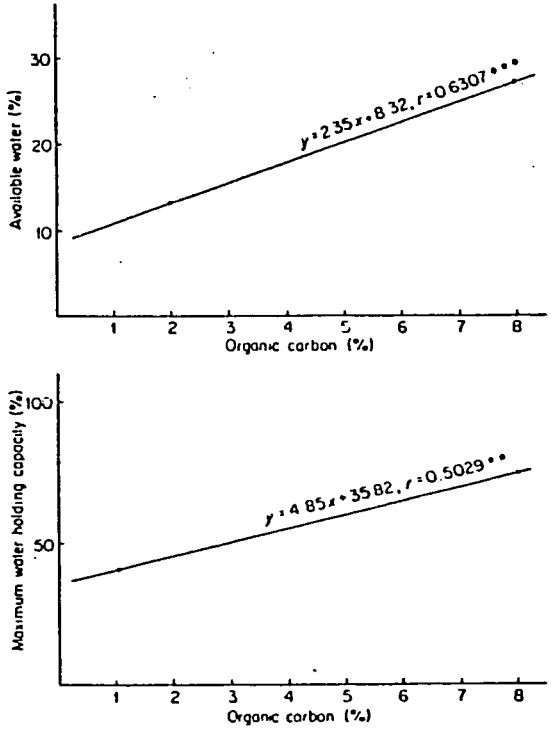

Figure 1.4 The relationship between organic matter content and soil-water retention

The neutron moisture meter has many advantages, but also limitations for general use in heterogeneous soils. For highly variable soils it is difficult to obtain a valid single calibration curve. Calibration is drastically influenced by physical factors such as bulk density, texture, and gravel concentration. Even the size and shape of gravels have a thermalizing effect on the neutron (Lal, 1974c; 1979a). Thus the neutron moisture meter has to be calibrated for each soil and each horizon, unless the soil happens to be uniform over the entire watershed. There may be large patches of rather uniform soil in some regions of the tropics, but these are exceptions rather than the rule.

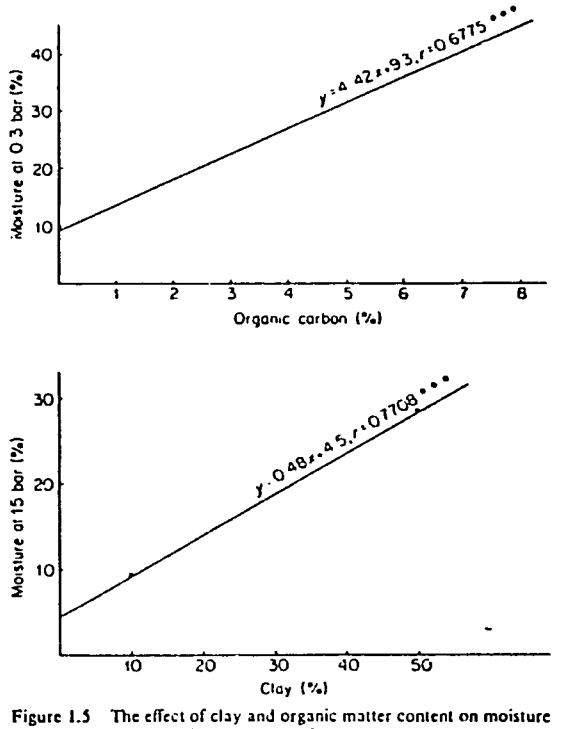

Figure 1.5 The effect of clay and organic matter content on moisture retention at 0.3 and 15 bar suctions

1.2.6. PLASTICITY AND ATTERBERG'S LIMITS

Plasticity characteristics and Atterberg's limits are important for developing tillage systems and for construction purposes. Where tillage is becoming unpopular because it is a major agent of accelerated soil erosion, investigations on plasticity limits are no longer a research priority. In addition, the surface horizons of a majority of soils in the humid regions are of coarse sandy loam or loamy sand texture and do not have plastic characteristics. With the exception of Vertisols and perhaps those soils developed on volcanic ash containing high amounts of

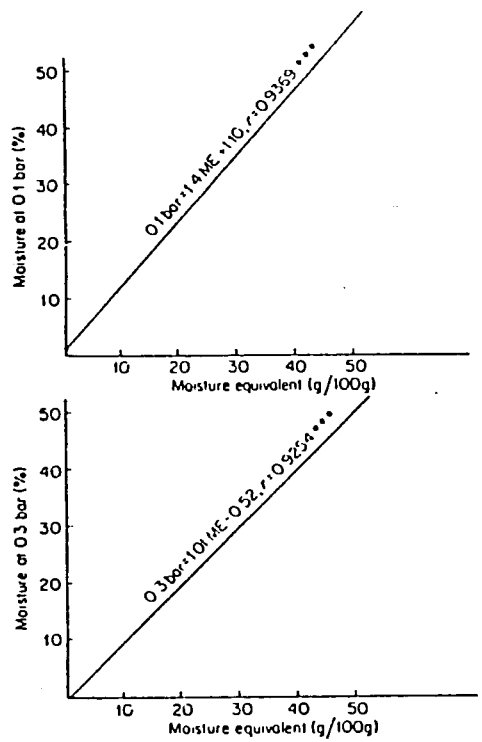

Figure 1.6 The relationship between moisture content at 0.1 and 0.3 bar suction with moisture equivalent

allophane, such as many soils of Hawaii, plasticity characteristics are generally not important for upland soils. Plastic characteristics may be important for lowland rice-growing soils of south eastern Asia where puddling is done to prevent deep percolation and to control weeds, though the usefulness of puddling is now widely questioned because of the economical availability of some herbicides.

Van Schuylenborgh (1954) indicated that air drying of samples of soils derived from volcanic ash, and containing a high proportion of allophane and amorphous material, can irreversibly affect the upper and lower plastic limits. Ahmad *et al.*

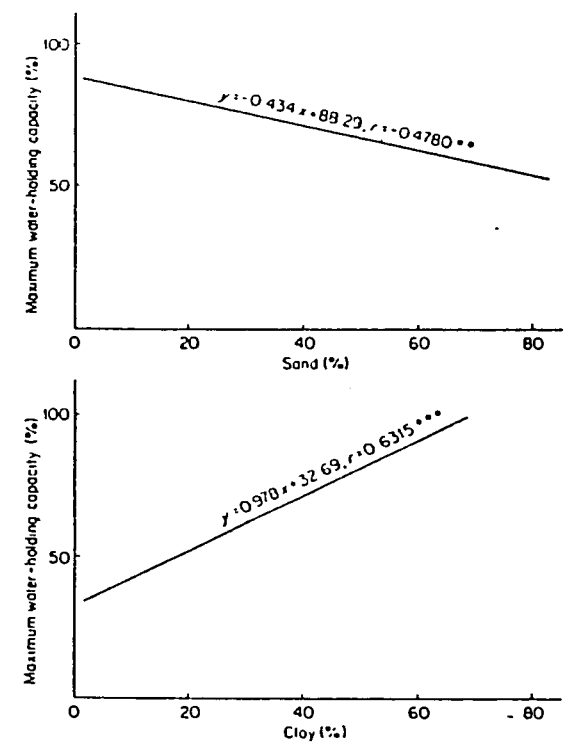

Figure 1.7 The effects of sand and clay content on the maximum water holding capacity

(1969) and El-Swaify *et al.* (1970) reported for some soils of Hawaii that plastic limits were independent of the nature of saturating cations, but were significantly dependent on clay type.

1.2.7. SOIL TEMPERATURE

Though, next to soil water, soil temperature is the most important physical factor affecting crop growth in the tropics, it has not been given the research priority it deserves. Many researchers and planners fail to recognize the importance of the adverse effect of supra-optimal soil temperatures on the growth and production potential of crops such as maize and soybeans. Though crops such as cowpea, pigeonpea, cassava, and upland rice have a higher optimum soil temperature, i.e. 30–35°C (Lal, 1974b), compared with that of maize and soybean, i.e. 25–30°C (Buckle and Grant, 1974; Lal, 1974a; Minchin *et al.*, 1976), they are by no means immune to the high soil temperatures of 40–50°C for 4–6 hr a day often found in the tropics. There is an urgent need to investigate the physical and physiological effects of high soil temperatures on crop growth.

A review of temperature relations of tropical soils (Lal, 1974a) indicated that, with a few exceptions, most of the research on soil temperature has been concerned with the effects of management. In Central Africa, Dupriez (1969) investigated the physics of propagation of the temperature wave in soil under different covers, and computed the phase angle and periodicity for different treatments.

Pereira *et al.* (1958) reported the effect of various types of covers on soil temperature for some Kenyan soils. The maximum soil temperature at 2.5 cm for bare ground was about 50°C compared with 35°C under grass. Temperature fluctuations at 20 cm were negligible. Soil temperatures under different tillage systems on some western Nigerian soils have been reported by Lal (Lal, 1976; Lal *et al.*, 1978). Soil temperatures of similar magnitude have also been observed in northeastern Thailand (Blevins *et al.*, personal communication to the author).

Some data on the effect of management on soil temperatures and crop growth are available from the tropics of Latin America. Lugo-Lopez and Capiel (1972) reported the mean maximum and minimum soil temperature at 5 cm depth for soils in Puerto Rico. The maximum temperature was 36°C at Rio Piedras, 39°C at Lajas, and 34°C at Fortuna.

Forest removal resulted in an increase of 20–25 degC (50 degC on bare ground) in soil temperature range compared with forested land in Guiana (Turiere, 1969). Similar effects of deforestation in Brazil are reported by Bastos *et al.* (1974). The effect of incorporating residue mulch on soil temperature for soils in Sao Paulo, Brazil, has been reported by Miyasaka *et al.* (1966); the maximum soil temperature on bare soil was 48°C compared with 21°C on mulched soil. Similarly, Menezes *et al.* (1973) and Sans *et al.* (1974) reported an increase in soil temperature with a decrease in degree of soil coverage. In addition to the direct

effects on crop growth, high soil temperatures also adversely affect soil processes such as symbiotic nitrogen fixation (Dobereiner, 1970).

1.2.8. METHODOLOGY FOR DETERMINING SOIL PHYSICAL CHARACTERISTICS

Literature cited indicates that considerable progress has been made in characterizing physical properties of some soils in different regions of the tropics. However, considering the importance of physical properties in developing viable systems of soil management, soil physicists have still a long way to go. The process has just begun. It is important therefore, particularly in this formative stage, that the methodology adopted by various researchers is uniform, so that results obtained from one soil and region can be compared with another. This approach will also avoid duplication of unnecessary and rather expensive research efforts.

The methodology proposed in Table 1.13 is by no means a final verdict, and is a mere suggestion of some techniques that may prove useful. For example, very often mechanical analyses conducted on the <2 mm fraction without any information on the amount of skeletal material contained in the original soil sample lead to erroneous conclusions. This type of textural analysis can be extremely misleading in the case of soils with high gravel contents. A similar argument applies to bulk density measurements for gravelly soils. As a rule of thumb, it is important to remember that whereas it may be possible to determine chemical characteristics on a well ground soil sample in the laboratory, soil physical properties cannot be adequately described by laboratory measurements. The process of soil sampling itself destroys the physical characteristics that are to be monitored. As much as possible, all physical characteristics such as pF curves, infiltration, saturated hydraulic conductivity, bulk density, and erodibility should be determined *in situ*. Field methods are laborious, time consuming, and expensive, but worth the effort. Because of the time and expense involved, the adoption of a uniform methodology is an important aspect of soil physics research.

The neutron moisture meter is a useful but an expensive tool. It only gives an indirect estimate of the amount of hydrogen atoms in the soil, that we hope is related to soil moisture content. There are many sources of error involved. A good calibration is the key to avoid some of these errors. Though the gravimetric method of soil moisture determination is simple and reliable, it has drawbacks that are avoidable. In a gravelly soil, it is important to make correction for gravel concentrations. One or two small stones can introduce a significant error in the moisture regime evaluation.

Studies on water balance and plant water requirements involving lysimeters require special planning. Weighing lysimeters, for the sole purpose of determining potential or even actual evapotranspiration, are too expensive. Instead of daily values, weekly averages can be obtained with simple drainage lysimeters. Though

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Table 1.13. Recommended methodology for determination of soil physical properties

Soil properties	Recommended methodology	Remarks
1. Texture	Hydrometer or pipette method following a thorough mechanical and chemical dispersion.	Proportion of skeletal material (>2 mm) must be determined.
2. Bulk density	(i) By core method for non-gravelly uniform soil. (ii) By excavation for soil under forest and for gravelly soils.	(i) Correction must be made for for gravel concentration. (ii) In addition to overall bulk density, bulk density of the fine earth material should be determined for gravelly soils.
3. Infiltration	(i) Sprinkling infiltrometer or field rain simulator. (ii) Two-dimensional infiltration test using spherical cavities.	Double-ring infiltrometer gives high values of infiltration rate because of lateral seepage below the ring.
4. Structure	(i) Rainfall acceptance test of Pereira with suitable modifications. (ii) Hénin index of aggregate stability. (iii) Kinetic energy required to disrupt aggregates. (iv) Pore size distribution computed from pF curves determined *in situ*.	For the regions with high earth-worm activity, characterization of worm channels may be an important aspect of soil structure.
5. Moisture potential profile	Using tensiometers or neutron probe.	Tensiometers do not perform well on gravelly soils and psychrometers are unsatisfactory for field measurements.
6. pF curves	(i) *In situ* measurements. (ii) Field capacity—*in situ*. (iii) Wilting point—compare the biotic method with that of undisturbed core samples subjected to different suctions.	Correction to be made for gravel concentration.
7. Soil moisture regime	Gravimetric method.	Neutron probe requires a careful calibration for each soil and each horizon.
8. Soil aeration	Sampling by diffusion tubes.	
9. Soil erodibility	Unit runoff plots in the field under natural rainfall conditions.	Laboratory simulator gives detachability rather than erodibility.
10. Saturated hydraulic conductivity	Field method using double-tube technique.	Saturated hydraulic conductivity below a water table can be determined by the auger-hole method.
11. Potential and actual evapotranspiration	Simple drainage lysimeters, either monolith or filled-in.	Weighing lysimeters are too expensive for these routine measurements.

monolith lysimeters are preferred, filled-in lysimeters can give good information, depending on the objectives of the investigation. A simple two-way comparison involving the effects on water requirements of two crops or two management systems may well be obtained by carefully constructed filled-in lysimeters.

REFERENCES AND BIBLIOGRAPHY

Ahmad, S., L. D. Swindale and S. A. El-Swaify, 1969, Effects of adsorbed cations on physical properties of Tropical Red and Tropical Black Earths. I. Plastic limits, percentage stable aggregates, and hydraulic conductivity, *J. Soil Sci.*, 20, 255–268.

Ahn, P., 1968, The effect of large scale mechanized agriculture on the physical properties of West African soils, *Ghana J. Agric. Sci.*, 1, 35–40.

Aina, P. O., R. Lal and G. S. Taylor, 1978, Relative susceptibility of some Nigerian soils to water erosion: A laboratory investigation, *Nigerian J. Soil Sci.*, 1 (In Press).

Alexander, E. B., 1955, Suelos del Departmento de Bolivar. *In* Organizacion de las Naciones Unidas para la Agricultura y la Alimentacion. Informe al Gobierno de Colombia sobre investigaciones de reconocimientos de suelos, FAO, Rome, 1969.

Alexander, E. B., 1973, A comparison of forest and savanna soils in north eastern Nicaragua, *Turrialba*, 23, 181–191.

Alvarado, A., and C. Lopez, 1971, Quimica y fisica de algunos Utisoles de Costa Rica, America Central, *Turrialba*, 21, 304–311.

Anaye, T. I., 1969, Sesquioxide status and particle size distribution in twelve Nigerian soils derived from sandstones, *African Soils*, 14, 85–96.

Ataga, D., 1973, Determining moisture content of some soils supporting the Palm (*Elaeis guineensis* Jacq) by the neutron moderation method, *J. Niger. Inst. Oil Palm Res, Benin City*, 5, 13–21.

Avella, T. A., and A. C. Rodriquez, 1973, Irrigation studies with the soils of the Coello district, *Revista del Instituto Colombiano Agropecuario*, 8, 87–115.

Babalola, O., 1972, Particle size analysis by the hydrometer method and its use in estimating the lower limit of available water, *Niger. Agric. J.*, 9, 49–55.

Babalola, O., and R. Lal, 1974, Neutron moisture meter and beta gauging technique to investigate plant–water relations for maize in western Nigeria. Isotopes and radiation techniques in soil physics and irrigation studies, IAEA, Vienna, pp. 335–347.

Babalola, O., and R. Lal, 1977a, Sub-soil gravel horizon and maize root growth, I. Gravel concentration and bulk density effects, *Plant and Soil*, 46, 337–346.

Babalola, O., and R. Lal, 1977b, Sub-soil gravel horizon and maize root growth, II. Effects of gravel size, inter-gravel texture, and natural gravel horizon, *Plant and Soil*, 46, 347–357.

Bastos, T. X., T. D. Diniz and A. S. De, 1974, Soil temperature in a humid tropical forest, *Boletin Tecnico do IPEAN (Brazil)*, 64, 73–83.

Benavides, J. Garcia, and L. Legarda, 1974, Prediccion de la humedad contenida en el suelo en clima muy húmedo-tropical (Turrialba, Costa Rica), *Agronomia Tropical*, 24, 299–315.

Bonnet, J. A., and M. A. Lugo Lopez, 1950, Relative erosiveness of Puerto Rico soils, *J. Agr. Univ. P. R.*, 34, 294–307.

Bonnet, J. A., and M. A. Lugo-Lopez, 1952, The rate of infiltration of lateritic soils, *J. Agr. Univ. P. R.*, 36, 161–166.

Borden, R. W., B. P. Warkentin and M. Coll, 1974, An irrigation rating for some soils in Antigua, W. I., *Tropical Agric. (Trinidad)*, 51, 501–513.

Boyer, J., 1970, Essai de synthèse des connaissances acquises sur les facteurs de fertilité des sols en Afrique intertropicale francophone, Committee on tropical soils, London, June 8–12, 1970.

Boyer, L., and A. Coimbeau, 1960, A study of the structural stability of some ferallitic soils from the Central African Republic, *African Soils*, 5, 25–42.

Bridge, B. J., S. Boonyoi and U. Arromratana, 1975, Properties affecting water entry in certain plain soils, Thailand, *Thai Journal of Agric. Science*, 8, 177–193.

Bruce-Okine, E., and R. Lal, 1975, Soil erodibility as determined by raindrop technique, *Soil Sci.*, 119, 149–157.

Buckle, J. A., and P. M. Grant, 1974, Effects of soil temperature on plumule growth and seedling emergence of maize (*Zea mays* L), *Rhodesian Journal of Agric. Research*, 12, 149–161.

Burgas, J., 1965, Elementos del balance hydrologico y los tipos de Clima de Venezuela estimados por el metode de Thornthwaite, *Agron. Trop.*, 15, 29–47.

Caguan, B., and G. Uehara, 1965, Soil anisotropy and its relation to aggregate stability, *Soil Sci. Soc. Amer. Proc.*, 29, 198–200.

de Camargo, A. P., 1962, Contribuicão para a determinacão do evapotranspiracão potential no estado de Sao Paulo, *Bragantia*, 21, 163–213.

Capiel, M., and R. G. Calvesbert, 1970, On the climate of Puerto Rico and its agricultural balance, *J. Agric. Univ. P. R.*, 60, 139–153.

Casagrande, A. A., G. O. Pereira and P. C. Corsini, 1975, Effect on the soil of mechanical cultivation and levels of fertilizer applied to a first ratoon of sugarcane crop, *Brasil Acucareiro*, 84, 30–49.

Casimiro, J. F., 1971, Soil water characteristics: Prediction of their curves under field conditions *Revista de Ciencias Agronomicas (Mozambique)*, 24, 345.

Chandler, J. V., R. C. Costas and R. W. Pearson, 1964, The intensive management of tropical forages in Puerto Rico, Bulletin 187, Univ. P. R. Agr. Exp. Stat. Rio Piedras, Puerto Rico.

Charoy, J., 1974a, Water dynamics in the tropical ferruginous soils of dune origin at Tarna and application to millet, groundnut, and a bare soil, *Agron. Trop.*, 29, 821–872.

Charoy, J., 1974b, Water dynamics in a soil type of the Goulbi de Maradi in Niger: Application to wheat irrigation and a cotton crop of the rainy season with supplementary irrigation, *Agron. Trop.*, 29, 982–994.

Chevalier, A., 1949, Points de vue noveux sur les sols d'Afrique tropicale sur leur degradation et leur conservation, *Bull. Agr. Congo Belge*, 40, 1057–1092.

Collinet, J., 1969, Contribution to the study of stone lines in the middle Ogoou's region (Gabon), *Cah. Pédol., ORSTOM*, 7, 1–42.

Colinet-Daage, F., and F. Cucalon, 1965, Characteristiques hydriques de certain sols des régions bananieres, *Equateur, Fruits*, 20, 19–73.

Colinet-Daage, F., and F. Cucalon, 1967, Caracteristiques de quelques sols d'Equateur derives de cendres volcaniques, 1er. Partie: Essai de caracterisation, *Cahiers ORSTOM, Série Pédologie*, 3–38.

Coimbeau, A., and G. Monnier, 1961, A method for the study of structural stability—application to tropical soils, *African Soils*, 6, 33–52.

Comerma, J. A., 1968, Pedogenesis de dos asociaciones de suelos en el nor centro de Venezuela, *Agronomia Tropical*, 18, 3–56.

Cooper, J. D., 1974, Soil water studies on Dimbolin Tea Estate, Kericho, Kenya, *Tea (Kenya)*, 14, 9–11.

Cooper, P. J. M., 1975, Studies on the soil atmosphere composition under maize, grass, and bare fallow in western Kenya, *East African Agric. & Forestry Journal*, 40, 313–331.

Cunningham, R. K., 1963, The effect of clearing a tropical forest soil, *J. Soil Sci.*, 14, 334–345.

Dabin, B., 1962a, Relations entre les propriétés physiques et la fertilité dans les sols tropicaux, *Ann. Agron.*, 13, 111–140.

Dabin, B., 1962b, Utilization of an index of structure for the determination of the physical qualities of tropical soils, *Trans. 7th Int. Cong. Soil Sci. Madison*, 7, 311–320.

Dagg, M., and J. C. Macartney, 1968, The agronomic efficiency of the N.I.A.E. mechanised tied ridge system of cultivation, *Expl. Agric.*, 4, 279–294.

Dancette, C., 1971, Control of the water supply of millet by the use of a neutron probe during two very different rainy seasons, *Agron. Trop.*, (*Paris*), 26, 721–735.

Dangler, R. W., S. A. El Swaify, L. R. Ahuja and A. P. Barnett, 1976, Erodibility of selected Hawaii soils by rainfall simulation, USDA, Agric. Res. Service, Western Region (USA), ARS -W-35, IRP.

De Leenheer, L., and M. De Boodt, 1959, Determination of aggregate stability by the change in mean weight diameter, *Mededl. Landb. Gent*, 24, 290–351.

Deshpande, T. L., D. J. Greenland and J. P. Quirk, 1968, Changes in soil properties associated with the removal of Fe and Al oxides, *J. Soil Sci.*, 19, 108–122.

De Vleeschauwer, D., R. Lal and M. De Boodt, 1979, Comparison of detachability indices in relation to soil erodibility for some important Nigerian soils, *Pedologr* (In Press).

Dijkerman, J. C., 1969, Soil resources of Sierra Leone, *African Soils*, 14, 185–206.

Dobereiner, J., 1970, Soil temperature effects on nitrogen fixation and growth of *Stylosonthes gracilis* and *Pueraria javanica*, *Pesqui. Agropecu. Bras.* (Rio de Janeiro), 5, 365–371.

Drover, D. P., 1966, Moisture retention in some soils of the Sudan, *African Soils*, 11, 483–497.

Dupriez, G. L., 1969, La température du sol en region équatorial africaine, Academie royale des sciences d'outre- Mei, classe des sciences technique N.S., 14–7, Bruxelles, 1969.

Eldin, M., and A. Daudet, 1969, L'evapo-transpiration potentielle: applications, *Agron. Trop.*, 24, 174–180.

El-Swaify, S. A., S. Ahmad and L. D. Swindale, 1970, Effects of adsorbed cations on physical properties of tropical red and tropical black earths. II. Liquid limit, degree of dispersion, and moisture retention, *J. Soil Sci.*, 21, 188–197.

Fernandez, B., and D. J. Sykes, 1968, Capacidado de campo ea retencao de agua en tres solos de Minas Gerais, *Revista Ceres*, 15, 1–39.

Forsythe, W. M., 1966, Progresos recientes en el analisis de las particulas de los suelos por medio del metodo del hidrometro, *Agronomia* (*Peru*), 33, 16–27.

Forsythe, W. M., 1976, Formula for calculating from weather data the residual soil moisture during soil drying, *Turrialba*, 26, 60–67.

Forsythe, W., and Y. R. Diaz- Romeo, 1969, La densidad aparente del suelo y la interpretacion del analisis de laboratorio para el campo, *Turrialba*, 19, 128–131.

Forsythe, W. M., S. A. Gavande and M. A. Gonzalez, 1969, Physical properties of soils derived from volcanic ash with consideration of some soils of Latin America, *In* Panel on Soils Derived from Volcanic Ash of Latin America, IICA, Turrialba, Costa Rica, 6–13 July 1969, pp. B 3.1–6.

Forsythe, W. M., and Orlando Vazquez, 1973, Effect of air drying on the water retention curves of disturbed samples of three soils of Costa Rica derived from volcanic ash, *Turrialba*, 23, 200–201.

Garay, A. F., 1966, Aeracion en un suelo de café, *Turrialba*, 16, 340–351.

Garcia Benavides, J., and B. L. Legarda, 1974, Prediction of soil moisture content in soil

in very humid, tropical climate (Turrialba, Costa Rica), *Agronomia Tropical* (*Venezuela*), 24, 299–315.

Gavande, S. A., 1968, Water retention characteristics of some Costa Rican soils, *Turrialba*, 18, 34–38.

Gavande, S. A., and M. A. Gonzalez, 1969, Irrigation requirement of sugarcane in the Alajuela area of Costa Rica, *Turrialba*, 19, 221–234.

Godefroy, J., and F. Jacquin, 1975, Relation between the structural stability of cultivated soils and organic manures in tropical conditions; comparison with forest soils, *Fruits* (*France*), 30, 596–612.

Gonzalez, M. A., and S. A. Gavande, 1969, Propiedades fisicas de algunos suelos dedicados al cultivo de la caña de azucar en Costa Rica, *Turrialba*, 19, 235–245.

Grohmann, F., 1960a, Distribuicão e tamanho de poros en três tipos de solos do estado de São Paulo, *Bragantia*, 19, 329–343.

Grohmann, F., 1960b, Analise de agregados de solos, *Bragantia*, 19, 201–213.

Grohmann, F., and A. Conagin, 1960, Tecnica para o estudo da estabilidade de agregados do solo, *Bragantia*, 19, 329–343.

Gumbs, F. A., 1974, Comparison of laboratory and field determined saturated hydraulic conductivity and prediction from soil particle size, *Trop. Agric.*, 51, 375–382.

Hamid, K. S., and M. A. Mustafa, 1975, Dispersion as an index of relative hydraulic conductivity in salt-affected soils of the Sudan, *Geoderma*, 14, 107–114.

Hénin, S., G. Monnier and A. Combeau, 1958, Methode pour l'étude de la stabilité structural des sols, *Ann. Agron.*, 9, 73–92.

Hernandez, Antonio A., and R. Guerrero Riascos, 1971, Algunas propiedades fisicas de dos suelos derivados de cenizas volcanicas, de pasto, colombia, determinadas por diferentes metodos, *Turrialba*, 21, 393–403.

Honisch, O., 1974, Water conservation in three grain crops in the Zambezi Valley, *Expl. Agric.*, 10, 1–8.

D'Hoore, J., 1968, Influence de la mise en culture sur l'évolution des sols dans la zone de forêt dense de basse et moyenne altitude, *African Soils*, 13, 155–168.

D'Hoore, J., et J. Fripiat, 1948, Recherches sur les variations de structure du sol à Yangambi, Série Scientifique 38, Publications de l'INEAC, Brassels.

Humbel, F. X., 1975, Study on soil macro-porosity by means of permeability tests: Applications of a percolation model to a ferrallitic soil in Cameroun, *Cahiers ORSTOM—Série Pédologie*, 13, 93–117.

Hurault, J., 1971, The erodibility of overgrazed soils in the Ademowe high plateaux (Cameroun): Infiltration studies, *Bull. Assoc. Fr. Etude Sol*, No. 1, 23–56.

Ilesanmi, O., 1972, Rainfall amounts and duration characteristics in Nigeria, *Nigerian Agric. Journal*, 9, 25–37.

Jones, M. J., 1973, The organic matter content of the savanna soils of West Africa, *J. Soil Sci.*, 24, 42–53.

Jones, M. J., 1976, Water movement and nitrate leaching in a Nigerian Savanna Soil, *Expl. Agric.*, 12, 69–79.

Kamerling, G. E., 1975, Studies in soil physics and agro hydrology on the young coastal plain of Suriname, South America, *De Surinaamse Landbouw*, 23, 31–37.

Kowal, J., 1968, Some physical properties of soils at Samaru, Zaire, Nigeria: storage of water and its use by crops. 2. Water storage characteristics, *Niger. Agric. J.*, 5, 13–20.

Kowal, J., 1969, Some physical properties of soils at Samaru, Nigeria; storage of water and its use by crops, *Niger. Afric. J.*, 6, 18–29.

Lal, R., 1974a, Soil temperature relations in tropical Africa and their effects on crop yield, FAO/UNDP International Expert Consultations on the use of Improved Technology

for Food Production In Rainfed Areas of Tropical Asia, Hyderabad, 24–28 Nov. 1974, India.

Lal, R., 1974b, Effect of constant and fluctuating soil temperature on growth, development, and nutrient uptake by maize, *Plant and Soil*, 40, 589–606.

Lal, R., 1974c, The effect of soil texture and density on the neutron and density probe calibration for some tropical soils, *Soil Sci.*, 117, 183–190.

Lal, R., 1976, No-tillage effects on soil properties under different crops in western Nigeria, *Soil Sci. Soc. Amer. J.*, 40, 762–768.

Lal, R., 1978, Effects of root zone temperature on some tropical crops, *Nigerian J. Science* (In Press).

Lal, R., 1979a, Concentration and size of gravel in relation to neutron moisture meter and density probe calibration, *Soil Sci.* 127:41–50.

Lal, R., 1979b, Physical properties and moisture retention characteristics of some Nigerian soils, *Geoderma* 21:209–223.

Lal, R., and D. J. Cummings, 1979, Changes in soil and micro climate by forest removal, *Field Crop Res.*, 2 (In Press).

Lal, R., G. F. Wilson and B. N. Okigbo, 1978, No-till farming after various grasses and leguminous cover crops on a tropical Alfisol. I. Crop performance, *Field Crops Research* 1, 71–84.

Landrau, Jr., P., M. A. Lugo Lopez, G. Samuels and S. Silva, 1954, Leaving sugarcane trash undisturbed on a lateritic soil compares favourably with currently used trash-disposal methods, *J. Agr. Univ. P. R.*, 38, 1–8.

Lawes, A. D., 1962, Rainfall conservation and yield of cotton in northern Nigeria, *Samaru Res. Bull.*, 16.

Leveque, A., 1969, The problem of stonelines. Preliminary observations on the gneiss–granite formation in Togo, *Cah. Pédol. ORSTOM*, 7, 43–49.

Liu, L. C., and H. R. Cibes-Viade, 1970, Leaching of Atrazine, Ametryne and Prometryne in the soil, *J. Agr. Univ. P. R.*, 54, 518.

Lognathan, S., and K. K. Krishnamoorthy, 1976, Influence of calcium on the physical properties of soil, *Madras Agric. J.* 63, 91–96.

Lugo-Lopez, M. A., 1951, Functional relationships between moisture at several equilibrium points and the clay content of tropical soils, *J. Agric. Univ. P. R.*, 35, 66–70.

Lugo-Lopez, M. A., 1952a, Available water capacity of the surface layers of various soils from the arid and semi-arid region of Puerto Rico, *J. Agric. Univ. P. R.*, 36, 134–140.

Lugo-Lopez, M. A., 1952b, Comparative values of various methods of approximating the permanent wilting percentage, *J. Agric. Univ. P. R.*, 36, 122–133.

Lugo Lopez, M. A., 1953, Moisture relationships of Puerto Rican Soils, Agr. Exp. Sta. Univ. P. R., Tech. Paper 9.

Lugo-Lopez, M. A., 1960, Pore size and bulk density as mechanical soil factors impeding root development, *J. Agric. Univ. P. R.*, 44, 40–44.

Lugo Lopez, M. A., 1969, Prediction of the erosiveness of Puerto Rican soils on the basis of the percentage of particles of silt and clay when aggregated, *J. Agric. Univ. P.R.*, 53, 187–190.

Lugo-Lopez, M. A., J. A. Bonnet, M. Rico Ballesres and G. Acevedo, 1957, Effect of soil structure stabilizer on the production of tobacco plants in the seedbed, *J. Agric. Univ. P. R.*, 41, 189–196.

Lugo Lopez, M. A., and M. Capiel, 1972, Seasonal changes in soil and air temperatures at 3 locations in Puerto Rico, *J. Agric. Univ. P. R.*, 56, 307–317.

Lugo-Lopez, M. A., and J. Juarez, Jr., 1959, Evaluation of the effects of organic matter

and other soil characteristics upon the aggregate stability of some tropical soils, *J. Agric. Univ. P. R.*, 43, 268–272.

Lugo-Lopez, M. A., P. Landrau, Jr. and G. Samuel, 1952, The handling of sugarcane trash. II. Effects of various practices on soil properties, *J. Agric. Univ. P. R.*, 36, 240–245.

Lugo-Lopez, M.A., J. Juarez, Jr. and J. A. Bonnet, 1968, Relative infiltration rate of Puerto Rican soils, *J. Agric. Univ. P.R.*, 52, 233–240.

Lugo-Lopez, M. A., and R. Perez-Escolar, 1959, Hydraulic conductivity of sub soil of Lajas Valley, *J. Agric. Univ. P. R.*, 43, 273–277.

Lugo-Lopez, M. A., and R. Perez-Escolar, 1969, A mathematical approach to evaluating the influence of various factors on the stability of aggregates in vertisols, *J. Agric. Univ. P. R.*, 53, 57–60.

Maclean, A. H., 1968, Soil properties of importance in irrigation planning, Internal Publication, Mt. Makulu Research Station, Zambia.

Marino, M. A., 1965, Etudio edafologico de algunos grandes grupos de suelo Venezolanos, *Agronomia Tropical*, 14, 223–251.

Martin, W. S., 1944a, Grass covers in their relation to soil structure, *Empire J. Expl. Agric.*, 12, 21–32.

Martin, W. S., 1944b, Soil structure, *E. Afr. Agric. J.*, 9, 189–195.

Martinez, M. B., and M. A. Lugo-Lopez, 1952, Tillage tests I. Effects of sub soiling and mole drainage upon the minimum infiltration capacity of a heavy clay soil of the tropics, *J. Agric. Univ. P.R.*, 36, 179–185.

Maynard, J., 1960, The residual effect of submersion on soil structure, *African Soils*, 5, 141–148.

Medina, H. P., and F. Grohmann, 1966, Disponibilidade de agua em alguns solos de Cerrado *Bragantia*, 25, 65–76

de Melo, V., 1974, Agricultural aptitude of the yellow red podsolic soil, *Boletin de Recursos Naturais de Sudane*, 12, 77–89.

Menezes, Dm. De, Pinto, M. and L. J. Vivaldi, 1973, *Pesqui Agropecu Bras. Ser. Agron., Rio de Janeiro*, 8/6, 39–51.

Mensah-Bonsu and R. Lal, 1975, Field and laboratory determination of hydraulic conductivity of an Alfisol in Nigeria, Vth Latin American Congress of Soil Sci., Medellin, Colombia.

Millar, A., 1973, Water relationships of 3 Chilean irrigated soils, *Turrialba*, 23, 275–283.

Minchin, F. R., P.A. Huxley and R. J. Summerfield, 1976, Effects of root temperature on growth and seed yield in cowpea (*Vigna unguiculata*), *Expl. Agric.*, 12, 279–288.

Miyasaka, S., A. P. de Camergo, R. Inforzato and T. Igue, 1966, Efeitos da cobertura e de incorpracao do solo, immediatamente antes do plantio, de diferentes formas de materia organica decomposta, na culture do Feijoeiro, *Bragantia*, 25, 349–363.

Mondardo, A., and M. J. Vieira, 1975, Encontro Nacional Sobre Pesquisas de erosao com simuladores de chuva, Fundacao Instituto Agronomico do Parana (IAPAR)

Monnier, G., 1965, Effect of organic matter on soil structural stability, *African Soils*, 10, 29–42.

Moore, A. W., 1967, Changes in soil moisture and organic matter under different covers at Ibadan, *Plant and Soil*, 27, 463–467.

Moss, P., 1964, Some aspects of the cation status of soil moisture. V. The effect of soil moisture tension on growth and cation uptake by plants, *Plant and Soil*, 20, 271–285.

Nye, P. H., and D. J. Greenland, 1964, Changes in soil after clearing tropical forest, *Plant and Soil*, 21, 101–112.

Obi, A. O., 1974, The wilting point and available moisture in tropical forest soils in Nigeria, *Expl. Agric.*, 10, 305–312.

de Oliveira, L. B., 1967, O estudo fisico do solo e a aplicacao racional de tecnicas conservacionistas, *Pesqui Agrop. Bras.*, 2, 281–285.

de Oliveira, L. B., H. D. Da Silveira and A. B. Campelo, 1968, Caracterizacao do adensamento no subsolo de uma area de 'Tabuleiro' de Estacao Experimental do Curado Recife, *Pesqui. Agrop. Brasil.*, 3, 207–214.

de Oliveira, L. B., A. Maria and C. M. Martins, 1966, Consideracoes sobre a umidade a 15 atmosferas e a umidade de murchamento (Metodo fisiologico) em solos do Nordeste, Boletin Tecnico N.2—Inst. Pesquisas e Experimentacao Agropecuria-as do Nordeste, Recife, Brazil.

Panabokke, C. R., 1967, Soils of Ceylon and use of fertilisers, Metro Printers, Austin Place, Colombia.

Panabokke, C. R., and J. P. Quirk, 1957, Effect of initial water content on the stability of soil aggregates in water, *Soil Sci.*, 83, 185–195

Panton, W. P., 1954, Soil survey report N. Federal Expt. Station, Serdang, *Malayan Agric. Journal*, 37, 136–145.

Parthasarthy, S., D. Purushothaman, K. Natarajan, N. Arunachalem and G. Rangaswami, 1976, Changes in certain physical properties of soil as influenced by Raji (*Eluecine coracana*) plant growth, *Madras Agric. J.*, 63, 249–252.

Pereira, H. C., 1941, Crop response to inter-row tillage, *Emp. J. Expl. Agric.*, 9, 29–42.

Pereira, H. C., 1955, The assessment of structure in tropical soils, *J. Agric. Sci., Camb.*, 45, 401–410.

Pereira, H. C., 1956, A rainfall test for structure of tropical soils, *J. Soil Sci.*, 7, 68–74.

Pereira, H. C., and V. R. S. Beckley, 1953, Grass establishment on eroded soil in a semi-arid African reserve, *Emp. J. Expl. Agric.*, 21, 1–14.

Pereira, H. C., E. M. Chenery and W. R. Mills, 1954, The transient effects of grasses on the structure of tropical soils, *Emp. J. Expl. Agric.*, 22, 148–160.

Pereira, H. C., and P. H. Hosegood, 1961, The productivity of tropical semi arid thorn-shrub under intensive management, *Emp. J. Expl. Agric.*, 29, 269–286.

Pereira, H. C., M. Dagg and P. H. Hosegood, 1964, A tillage study in Kenya Coffee. IV. The physical effects of contrasting tillage treatments over thirty cultivation seasons, *Emp. J. Expl. Agric.*, 32, 31–34

Pereira, H. C., P. H. Hosegood and M. Dagg, 1967, Effects of tied ridges, terraces, and grass leys on a lateritic soil in Kenya, *Expl. Agric.*, 3, 89–98.

Pereira, H. C., and P. A. Jones, 1954a, Field responses by Kenya Coffee to fertilizers, manures, and mulches, *Emp. J. Expl. Agric.*, 22, 23–36.

Pereira, H. C., and P. A. Jones, 1954b, A tillage study in Kenya Coffee II. The effects of tillage practices on the structure of the soil *Emp. J. Expl. Agric.*, 22, 323–331.

Pereira, H. C., R. A. Wood, H. W. Brzostowski and P. H. Hosegood, 1958, Water conservation by fallowing in semi-arid tropical East Africa, *Emp. J. Expl. Agric.*, 24, 213–228.

Perez Escolar, R., J. Juarez, Jr., J. A. Bonnet and M. A. Lugo Lopez, 1974, Moisture retention in the organic soils of Cano Tiburones, *J. Agric. Univ. P.R.*, 58, 225–229.

Perez-Escolar, R., and M. A. Lugo Lopez, 1968, Nature of aggregation in two tropical soils of Puerto Rico, *J. Agric. Univ. P. R.*, 52, 227–232.

Perez-Escolar, R., and M. A. Lugo Lopez, 1969, Availability of moisture in aggregates of various sizes in a typical Ultisol and a typical Oxisol of Puerto Rico, *J. Agric. Univ. P.R.*, 53, 113–117.

Pidgeon, J. D., 1972, The measurement and prediction of available water capacity of ferrallitic soils in Uganda, *J. Soil Sci.*, 23, 431–444.

Pla, I., 1968, Variantes y utilidad de la 'mesa de tension' en el estudido de les relaciones suelo-agua, *Rev. Fac. Agron. Venezuela*, 5, 57–75.

Pomeroy, D. E., 1976, Some effects of mound building termites on soils in Uganda, *J. Soil Sci.*, 27, 377–394

Rajamannar, A., and C. R. Venkataraman, 1976, Influence of clay and silt on the physical properties of major soil groups of Madurai district (Tamil Nadu), *Madras Agric. J.*, 63, 160–164.

Riquier, J., 1969, Contribution to the study of stonelines in tropical and equatorial regions, *Cah. Pédol. ORSTOM*, 7, 71–112.

Roberts, R. C., 1933, Structural relationships in a lateritic profile, *Am. Soil Surv. Assoc. Bull.*, 14, 88–90.

Roeder, M., and E. Bornemisza, 1968, Algunas propiedades de unsuelo de la region Amazonica del estado de Maranhao, Brasil, *Turrialba*, 18, 39–44.

Roose, E. J., 1973, Dix sept années des mésures experimentales de l'erosion et du ruissellement sur un sol ferrallitique sableux de basse Côte de Ivoire Contribution a l'etude de l'érosion hydrique en milieu intertropical, ORSTOM, Abidjan, These Doct. Ing., Fac. Sci. Abidjan, 1973.

Rose, C. W., 1960, Soil detachment caused by rainfall, *Soil Sci.*, 89, 28–35.

Rose, C. W., 1962, Some effects of rainfall, radiant drying, and soil factors on infiltration under rainfall into soils, *J. Soil Sci.*, 13, 286–285.

Ryski, L. J. Nothmann and M. Spiegelman, 1976, Effects of soil temperature on the development of young egg plants (*Solanum melongena*), *Expl. Agric.*, 12, 273–277.

Sans, L. M. A., J. A. Menezes Sobrinho, R. F. De Novais and H. L. Dos Santos, 1974, The effect of mulching on moisture content and some chemical characteristics of the soil under a garlic crop, *Revista Ceres (Brasil)*, 21, 91–104.

Santamaria, F., 1965, Geographical distribution of the 'arrenite' (pavement) horizon in Venezuela, *Bull. Soc. Venz. Cienc. Nat.*, 25, 350–354.

Schroo, H., 1976, Soil productivity factors of the soils of the Zandery formation in Surinam, *De Surinaamse Landbouw*, 24, 68–84.

Segalen, P., 1969, Rearrangement of materials in soils and the formation of stonelines in Africa, *Cah. Pédol. ORSTOM*, 7, 113–311.

Sharma, M. L., and G. Uehara, 1966, Influence of soil structure on water relations in low humic latosols. I. Water retention, *Soil Sci. Soc. Am. Proc.*, 32, 765–770.

Sharma, M. L., and G. Uehara, 1968, Influence of soil structure on water relations in low humic latosols. II Water movement, *Soil Sci. Soc. Am. Proc.*, 32, 770–774.

Shukla, L. N., 1974, Soil compaction due to harvest traffic in sugarcane fields on a Lajas valley farm of Puerto Rico, *J. Agric. Univ. P. R.*, 53, 279–292.

da Silva, L. F., A. C. C. P. Dias and A. A. O. de Melo, 1975, Characteristics and management properties of Oxisols in southern parts of Bahia, *Revista Theobroma (Brasil)*, 5 (4), 23–34.

Smith, R. M., and C. F. Cernuda, 1952, Some characteristics in the macro structure of tropical soils in Puerto Rico, *Soil Sci.*, 73, 183–192.

Smyth, A. J., and R. J. Montgomery, 1962, Soils and land use in central and western Nigeria, Govt. Printer, Ibadan, Nigeria.

Sykes, J., 1969, Reconsideracao do conceito de umidade de murchamento permanente, *Turrialba*, 19, 525–530.

Sys, C., 1972, Caracterisation morphologique et physico chimique de profil types de l'Afrique centrale, INEAC Hors Serie, Brussels, 497 pp

Taylor, M. S., 1974, The effect of soil aggregate size on seedling emergence and early growth, *E.A. Agric. For. J.*, 40, 204–213

Thomas, M. DX., Æ-Eæ, *Tropical Geomorphology*, A study of weathering and land form development in warm climates, Macmillan, London, 332 pp

Tran-Vinh-An and H. Nguba, 1971, Contribution à l'étude de l'eau utile de quelques sols du Zaire, *African Soils*, 16, 91–103.

Turienne, J. F., 1969, Clearing and burning as soil preparation, modification of physical and chemical characteristics of upper soil horizons, 7th Congress Caribbean Food Crops Society, 1969.

Uehara, G., K. W. Flach and G. D. Sherman, 1962, Genesis and morphology of certain soil structural types in Hawaiian Latosols and their significance to agricultural practices, Trans. Joint Meet. Comm. IV and V, Int. Soc. Soil Sci., New Zealand, pp. 264–269.

Uehara, G., T. C. Juang and M. Isoba, 1972, Soil water infiltration and redistribution under furrow and sprinkler irrigation, *Proc. Int. Soc. of Sugarcane Technologist; 14th Cong.*, Franklin Press, Baton Rogue, Louisiana (USA), pp. 894–898.

Van Schuylenborgh, J., 1954, The effect of air drying of soil samples upon some physiological properties of soils, *Neth. J. Agric. Sci.*, 2, 50–57.

Van Wambeke, A. R., 1962, Criteria for classifying tropical soils by age, *J. Soil Sci.*, 13, 124–132.

Wahab, A., H. Talleyrand and M. A. Lugo-Lopez, 1976a, Rooting depth, growth and yield of sorghum as affected by soil water availability in an Ultisol and Oxisol, *J. Agric. Univ. P. R.*, 60, 329–335.

Wahab, A., H. Talleyrand and M. A. Lugo-Lopez, 1976b, Rooting depth, growth, and yield of corn as affected by soil water availability in an Ultisol and an Oxisol, *J. Agric. Univ. P. R.*, 60, 316–328.

Warkentin, B. P., 1974, Physical properties related to clay minerals in soils of the Caribbean, *Trop. Agric.*, 51, 279–287.

Watson, J. P., 1962, The soil below a termite mound, *J. Soil Sci.*, 13, 46–51.

Weert, R. Van Der, and K. J. Lenslink, 1974, Moisture characteristics of a number of soils in the interior of Surinam, *Surinaamse Landbouw Paramaribo*, 22, 13–22.

Whiteman, P. T. S., 1975, Moisture conservation by fallowing in Botswana, *Expl. Agric.*, 11, 305–314.

Wilkinson, G. E., 1975, Effect of grass fallow rotations on the infiltration of water into a savanna zone soil of northern Nigeria, *Trop. Agric. (Trinidad)*, 52, 97–104.

Wilkinson, G. E., and P. O. Aina, 1976, Infiltration of water into two Nigerian soils under secondary forest and subsequent arable cropping, *Geoderma*, 50, 51–59.

Wolf, J. M., and M. Drosdoff, 1936a, Soil water studies in Oxisols and Ultisols of Puerto Rico. I. Water movement, *J. Agric. Univ. P. R.*, 60, 375–385.

Wolf, J. M., and M. Drosdoff, 1976b, Soil water studies in Oxisols and Ultisols of Puerto Rico. II. Moisture retention and availability, *J. Agric. Univ. P. R.*, 60, 386–394.

Wunsche, W. A., 1977, Experimentos con la conservacion del agua y el control de la erosion con metodes de manejo de suelos, en Rio Grande del sur, Brasil, Trabajo presentado en la Reunion-Taller sobre conservacion y manejo de suelos en America Latina, Lima, Peru, 3 a 15 de Octubre de 1977.

Wischmeier, W.H. 1976. Use and misuse of the universal soil loss equation. Journal of Soil and Water Conservation 31:5-9.

Appendix A

Use and misuse of the universal soil loss equation

W. H. Wischmeier

The universal soil loss equation permits methodical decision-making in soil conservation planning on a site basis. Nearly two decades of widespread use in soil conservation district programs have confirmed its reliability when used as designed. But sometimes the equation is also used for purposes that it was not designed for, simply because it seems to meet the need better than any other tool available. Such extensions of its application should not be categorically discouraged, but proper precautions are needed to avoid possible misuse or false conclusions.

Design and Characteristics

The universal soil loss equation was designed to predict soil loss from sheet and rill erosion. As used here, soil loss must be distinguished from field sediment yield. The soil loss predicted by the equation is that soil moved off the particular slope segment represented by the selected topographic factor. This is the information needed for soil conservation planning. But in most cases, not all of the sediment produced on the slopes leaves the field. A field's sediment yield is the sum of the soil losses on the slope segments minus deposition in depressions within the field, at the toe of slopes, along field boundaries, and in terrace channels. The equation does not account for this deposition.

Neither is erosion synonymous with soil loss. The soil loss from a contoured and stripcropped slope, for example, is much less than the amount of soil eroded between the sod strips.

Many variables and interactions influence sheet and rill erosion. The universal soil loss equation groups these variables under six major erosion factors, the product of which, for a particular set of conditions, represents the average annual soil loss.

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The equation is

$$A = RKLSCP$$

where A is the average soil loss for the time interval represented by factor R, expressed in the dimensions of factor K (usually tons/acre). If the value of R is obtained from the iso-erodent map, A will be the average annual soil loss.

R is a measure of the erosive forces of rainfall and runoff. It usually equals the local value of the erosion index (EI) rainfall parameter, but two exceptions will be pointed out.

K reflects the inherent erodibility of a particular soil. For a given soil, it equals the average soil loss per unit of factor R from a 72.6-foot length of 9 percent slope in clean-tilled continuous fallow. It can be measured on other slope gradients and adjusted to the 9 percent standard with a slope-effect formula. It can also be computed as a function of the soil's physical and chemical properties.

L and S are dimensionless factors that adjust the soil loss estimate for effects of length, steepness, and shape of the field slope.

C introduces the effects of the cropping system and management variables on soil loss.

P reflects the benefits of supporting practices, such as contouring and stripcropping.

The equation computes long-term average annual soil losses for specific combinations of physical and management conditions. It was designed for field use by soil conservation planners and technicians. This required that it be easy to solve and include only factors whose values at a particular site can be determined from available data. Some potential details and refinements were sacrificed in the interests of utility.

Each of the six erosion factors in the equation is a function of numerous secondary variables and interaction effects that must be considered when computing local values of the factors. For field application, local values for the equation's factors are obtained from published charts and tables (*5, 6, 7, 8, 9, 10*). These chart values were developed from research data collected at 48 stations in 26 states. They average the effects of random fluctuations in many of the variables, which can bias short-term soil losses.

The relation of a particular parameter to soil loss is often appreciably influenced by the levels at which other parameters are present. To the extent that these interaction effects could be evaluated from existing data, they are reflected in the equation through the established procedures for computing local factor values. Factor R reflects the interaction of storm size and rain intensities. The soil loss ratios and EI distribution curves used to evaluate C account for the interactions of the crop system with management and rainstorm distribution. The relation of slope steepness to effectiveness of contouring and stripcropping is reflected in the table of P values. There are, however, indications of interactions between soil, topography, and surface conditions that require further research before their effects can be incorporated in the factor-evaluation procedures.

Confidence Limits

Soil losses computed by the equation must be recognized as the best available estimates rather than as absolute data. All empirically derived prediction equations involve experimental error and potential estimation error due to the effects of unmeasured variables.

The prediction accuracy of the equation was checked against 2,300 plot-years of soil loss data from 139 field plots at widely scattered locations (*4*). The published iso-erodent map, EI distribution curves, table of soil loss ratios, and slope-effect chart were used to evaluate the equation factors and predict the average annual soil loss for each of the 189 plots. The predicted loss for each plot was then compared with the measured average annual soil loss for the period of research record on that plot.

The mean annual soil loss for the 189-plot sample was 11.3 tons per acre. The average prediction error was 1.4 tons, and 159 of the 189 predictions (84 percent) were within 2 tons of the measured losses. About 5 percent of the predictions differed from the measured losses by a little more than 4.5 tons (40 percent of the overall mean). Significantly, however, two-thirds of the 88 deviations that exceeded 1 ton were from comparisons with soil loss records short enough to represent less than half of a normal 20- to 22-year rainfall cycle (*2*). They were probably biased by cyclical effects as a result. When its factors are evaluated from the tables and charts, the equation predicts the average annual loss for a 22-year rainfall cycle.

Designed Uses for the Equation

Applications for which the equation was specifically designed and field-tested (*10*) include:

1. Predicting average annual soil movement from a given field slope under specified land use and management conditions.

This can be the average annual soil loss from a given crop system, but it need not be. It can be the long-term average for a particular crop year in a rotation, such as second-year corn in a wheat-meadow-corn-corn system, or the year when a field in a no-till system is plowed for weed or insect control. If R and C are appropriately selected, the prediction can be the long-term average loss for a particular crop stage, for example, the seedbed and establishment period for corn in a given crop and management system. The length of the crop-system interval for which the average soil loss is computed is not restricted, but the computed soil loss will be the estimated average rate for enough recurrences of that interval on the given field to average out the short-term effects of random variables and their interactions with other factors.

2. Guiding the selection of conservation practices for specific sites.

This is the application for which the equation was initially intended and has made its greatest contribution. For this purpose, it is used together with a specified tolerance limit on average annual soil loss. The product of factors R, K, L, and S for a given site determines the basic soil loss index for that site. The tolerance limit divided by this index is the maximum value of factor C that will meet the established goal without special supporting practices. If supporting practices like contouring or stripcropping are added, the maximum allowable C value is increased by a factor of 1/P. Entering the local table of C values with the threshold value derived by this method provides a list of the various alternative combinations of crop system and management practices that will hold the average annual soil loss from the field below the prescribed tolerance level. A farmer can then select from this list the combination that is best suited to his production plan and economic situation.

3. Estimating the reduction in soil loss attainable from various changes that a farmer might make in his cropping system or cultural practices.

4. Determining how much more intensively a given field could be safely cropped if contoured, terraced, or stripcropped.

5. Determining the maximum slope length on which given cropping and management systems can be tolerated in a field.

Maximum lengths so computed must be compared with the critical-length limits for effectiveness of the practices considered. When these limits are

exceeded, P and C rapidly approach the values that these factors would merit without the practices.

6. Providing local soil loss data for Soil Conservation Service technicians and others to use when discussing erosion control needs and conservation plans with farmers or contractors.

The equation enables the technician to tell a farmer about how much soil he is losing by erosion and how much he could reduce the loss using other practices. The data can also be translated into economic effects.

7. Estimating soil losses from construction, rangeland, woodland, and recreational areas (7, 9).

These estimates are less accurate than cropland estimates because C values for these conditions have not been determined as accurately as for cropland conditions. When they are, the soil loss estimates should be as good.

Misuses and Misinterpretations

Applying the universal soil loss equation in new geographic regions or for purposes that it was not specifically designed for does not usually constitute a misuse. But such adaptations by users who are only superficially acquainted with the equation as a handbook formula can lead to misuse or false conclusions. Applying the equation to situations for which its factor values cannot be determined from existing data with acceptable accuracy is a misuse. Failure to recognize the true interpretations of its factors and limitations of the factor-evaluation formulas and charts can lead to false interpretation of the equation solutions.

Specific hazards and limitations that must be recognized can be pointed out in relation to four problem areas.

Watershed Sediment Yields

The equation can be properly used to compute the total average annual soil loss from sheet and rill erosion within a particular watershed. However, for computational purposes, a complex watershed must be subdivided into areas for which representative values of the six factors can be defined. Applying the equation to a complex watershed by using overall averages of slope length and gradient with estimated watershed-average values for factors K and C would be incorrect. To use the equation correctly, the combination of selected factor values must reflect how the parameters are associated in each subarea.

The sum of the soil loss estimates for the individual tracts in a drainage area approximates the amount of soil moved from its original position. To compute the sediment yield in the drainage area, this estimate must be reduced to compensate for deposition at the toe of field slopes, in field boundaries, in depressions, in constructed sediment basins and traps, and along the path traveled by the runoff as it moves from the field to a stream. Sediment additions from sources along this path must also be taken into account.

The gross soil loss estimated by the equation should be used together with a deposition equation and estimates of sediment additions from gully, streambank, and channel erosion. No deposition equation is now available, and a sediment delivery ratio is used as a lumped accounting for sediment load changes below the areas for which gross soil loss is computed. A sediment yield estimate obtained by this procedure is a long-time average for the particular watershed conditions. Neither the gross soil loss nor the delivery ratio can presently be predicted on an individual runoff-event basis.

Predicting Specific Soil Loss Events

If the equation is applied to a specific rain event, using storm EI for R and the relevant cropstage soil loss ratio for C, it will estimate the average soil loss for numerous recurrences of this event on that field and in that cropstage period. However, the soil loss in any one of these events may differ widely from this average in either direction.

Soil losses during specific storms and in specific years are greatly influenced by irregular, temporal fluctuations in secondary parameters that temporarily affect the equation factor values. Since the positive and negative effects of these fluctuations tend to balance over a long time period, they do not invalidate the equation for predicting long-term average soil losses for specific land areas and management conditions. But an equation designed to predict specific soil loss events must account for their temporary effects.

Following are some of the fluctuating variables relative to factors R, K, and C:

R values obtained from the iso-erodent map are locational average annual values of the EI parameter for 22-year weather cycles. EI values for a specific year within that period usually range from less than half to more than double the 22-year average and are influenced by large random variations as well as cyclical effects. Even 10-year averages can be significantly biased.

Annual and maximum storm EI values tend to follow a log-normal frequency distribution, and the probabilities for exceeding various magnitudes can be computed from long-term rainfall records. Specific probabilities for 181 locations were published in Agriculture Handbook No. 282 (12). These can be used to compute rough approximations of soil loss probabilities on a given field, but they do not account for differences due to associated deviations in other factors from their average values at the location.

The soil-erodibility factor, K, is an average for a given soil. However, the soil loss per unit of EI on a given field varies from storm to storm due to fluctuations in antecedent surface conditions and storm characteristics.

Until runoff begins, soil loss is negligible. The threshold rain amount, intensity, or EI for insipient runoff is a function of the interrelations of many variables. Under average antecedent conditions, rains of 0.5 inch or less between breaks of 6 hours or more rarely produce significant soil losses. These rains were omitted from the calculations of average annual EI values. But soil loss from rains of more than 0.5 inch is also affected by variations in time to insipient runoff. When rain falls on relatively dry, freshly tilled soil, most of the water may infiltrate before runoff begins, resulting in a low average soil loss per unit of EI for that storm. When rain falls on presaturated soil, runoff begins quickly and most of the rain becomes runoff. Such rains usually produce above normal soil loss per EI unit. In a low rainfall year, most or all rains may occur on dry, receptive soil. In an extremely wet year, the probability of erosive rainstorms striking a presaturated soil is much greater.

Some rains are accompanied by high winds that increase the velocity and impact energy of raindrops. Others occur in a fairly calm atmosphere. Some storms begin with a very high intensity and seal the surface quickly so that trailing lower intensities encounter a low infiltration rate. In other storms the moderate intensities precede the high intensities. In some seasons the soil is cultivated when wet and remains clotty. In other seasons it is cultivated when soil moisture is ideal for fine pulverization.

A claypan or fragipan 18 inches below the surface may substantially influence permeability in early spring or in a very wet growing season and yet have no significant effect on infiltration rates during intense thunderstorms on dry soil.

These and other random variations cannot be predicted for a specific point in time, and their immediate primary and interaction effects have not been numerically evaluated. Using the average soil loss per EI unit for a

particular soil is adequate for predicting long-term average soil loss but inadequate for estimating soil losses during specific storms or in specific years.

The cover and management factor, as derived for field use, also includes some averaging of secondary variables. The soil loss ratios tabulated in Agriculture Handbook No. 282 are averages for cropstage periods that cover time intervals of one to three months (*3*, *10*). Early in a cropstage period, the ratio will usually be higher than average because the development of cover is gradual. Later in the period it will be lower than average. In a poor growing season the ratio will be above average because cover and water use by transpiration are below normal. In a highly favorable growing season the ratio will be below average. The residual effects of turnplowed meadows vary according to their quality. Cover effect in a specific year may also be substantially influenced by deviation of the seasonal distribution of EI from the normal for the locality. The EI distribution curves published in Agriculture Handbook 282 represent regional 22-year averages.

A crop canopy or conservation tillage practice may delay the start of runoff long enough to be 100 percent effective for moderate storms on a given field and yet allow substantial erosion by prolonged periods of runoff. Average increases in time to insipient runoff that result from crop canopies or special tillage practices are reflected in the tabulated crop-stage soil loss ratios used for derivation of local C values, but deviations from these averages can substantially affect losses during specific storms.

Sources of Error in Factor Values

Perhaps the greatest potential source of prediction error is superficiality in selecting factor values. The conditions to be evaluated must be clearly defined. Soil, cover, and management conditions may not match any specific lines in the tables of K values, soil loss ratios, and P values. Interpolated values guided by judgment and knowledge of the situation can then be much more accurate than values selected directly from the tables. If the selected values do not truly represent the conditions to be evaluated, neither will the computed soil loss.

Other potential sources of error include:

1. Evaluating the factors on too broad a base, such as a single C value for all cropland or all corn land.

2. Applying C and P values from the handbook indiscriminately without considering length limits beyond which the practices become ineffective. When a practice breaks down from too much accumulation of runoff, the effective C or P value increases rapidly.

3. Extrapolating factor relationships far beyond the range of the data from which they were derived. This hazard, always speculative, applies primarily to L and S. Until research can expand the data, extrapolations of the formulas provide the best information available, but their limitations must be recognized.

4. Defining slope length incorrectly. The effective slope length is the distance from the point of origin of overland flow to the point where either the slope decreases enough that deposition begins or the runoff water enters a well-defined channel (*10*). Thus, a slope length is measured to a well-defined channel and does not include the length of the channel. Neither is a slope length terminated by a pronounced change in gradient or land use unless the runoff is diverted.

5. Evaluating irregular slopes. The slope-effect chart reflects relationships for uniform gradients. A convex slope loses more soil than an equivalent uniform slope, and a concave slope loses less. It is logical and correct to divide appreciably irregular slopes into relatively uniform segments for evaluation, but the segments cannot be treated as independent slopes if one segment receives runoff from another. A method of computing LS for irregular slopes was published in 1975 (*1*, *6*).

6. In some earlier publications, factor R, unfortunately, was categorically equated with the local EI value. R should be defined as the rainfall and runoff erosivity. EI generally reflects this combination, but there are two exceptions.

First, EI does not reflect the erosive potential of runoff that is not directly associated with rainfall. In the Palouse region of the Northwest, probably 90 percent of the erosion is caused by runoff from thaw and snowmelt. The erosive potential of this runoff must be added to the local EI value to evaluate R.

Second, on the Southeast Coastal Plains, computed annual EI values are very high because of the hurricane-associated storms and the slope gradients are quite small. Field observers have suggested that the normally computed EI values seem to overestimate soil loss for this condition. A logical assumption is that this is largely attributable to shielding of the soil surface by excessive ponding of rainfall during the prolonged periods of high intensities. But further study is needed to determine the variables and interactions responsible for the apparent overestimation.

Generating Research Data

If the universal soil loss equation is used to generate soil loss data for correlation with other parameters, as in evaluation of upslope deposition or sediment delivery ratios, precision in factor evaluation is much more essential than for conservation planning guides. This also applies when checking the equation against a local sample of plot data.

The researcher needs to exercise judgment in selecting pertinent factor values that will account for differences from averages and for differences from field conditions and normal field operations. For example, the P value for farming across slope on a narrow plot is likely to be at least 50 percent lower than the contour factor for a wide field.

Changing a rotation or management practice does not immediately change the residual effects. The preceding system may remain influential for several years. Plowing a plow with a small garden tracter or a spade may leave much more plant residue on or at the surface than moldboard plowing and thus merit use of a much lower soil loss ratio than that listed for the same crop system under field conditions. Also, problems pointed out in the last two preceding subsections become particularly relevant when the equation is used to generate data for analysis of other factor relations.

REFERENCES CITED

1. Foster, G. R., and W. H. Wischmeier. 1974. *Evaluating irregular slopes for soil loss prediction.* Trans., ASAE 17(2): 305-309.
2. Newman, J. E. 1970. *Climate in the 1970s.* Crops and Soils 22(4): 9-12.
3. Wischmeier, W. H. 1960. *Cropping-management factor evaluations for a universal soil-loss equation.* Soil Sci. Soc. Am. Proc. 24(4): 322-325.
4. Wischmeier, W. H. 1972. *Upslope erosion analysis.* In *Environmental Impact on Rivers.* Water Resources Publ., Fort Collins, Colorado.
5. Wischmeier, W. H. 1973. *Conservation tillage to control water erosion.* In *Conservation Tillage*, the proc. of a national conf. Soil Cons. Soc. Am., Ankeny, Iowa. pp. 133-141.
6. Wischmeier, W. H. 1974. *New developments in estimating water erosion.* In *Land Use: Persuasion or Regulation?* Proc., 29th Ann. Meet. Soil Cons. Soc. Am., Ankeny, Iowa. pp. 179-186.

7. Wischmeier, W. H. 1975. *Estimating the soil-loss equation's cover and management factor for undisturbed areas.* ARS-S-40. Agr. Res. Serv., U.S. Dept. Agr., Washington, D. C. pp. 118-124.
8. Wischmeier, W. H., C. B. Johnson, and B. V. Cross. 1971. *A soil erodibility nomograph for farmland and construction sites.* J. Soil and Water Cons. 26(5): 189-193.
9. Wischmeier, W. H., and L. D. Meyer. 1973. *Soil erodibility on construction areas.* Spec. Rpt. 135. Highway Res. Bd., Natl. Acad. Sci., Washington, D. C. pp. 20-29.
10. Wischmeier, W. H., and D. D. Smith. 1965. *Predicting rainfall-erosion losses from cropland east of the Rocky Mountains.* Agr. Handbook No. 282, U.S. Dept. Agr., Washington, D. C. 47 pp.

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Roose, E.J. 1977. Use of the universal soil loss equation to predict erosion in West Africa. In Soil erosion: Prediction and control. Soil Conservation Society of America, Special Publication no. 21. Ankeny, Iowa.

Use of the universal soil loss equation to predict erosion in West Africa

E. J. Roose

Erosion has for centuries been an obstacle to development. Consequently, man has tried to remedy this in diverse ways (terraces, reservoirs, itinerant cultivation, etc.) that more or less take into account climatic, economic, and human circumstances. With the purpose of rationalizing the choice of erosion control methods, several authors have formulated equations linking solids transport of field scale to causal and conditional erosion factors.

Among these attempts, the universal soil loss equation is by far the best known and the most widely used on other continents as well as in the United States. This empirical equation is based on the statistical analysis of more than 10,000 plot-years of data of sheet and rill erosion on plots and small watersheds. The equation is

$$A = RKSLCP \qquad [1]$$

in which erosion (A) is a multiplicative function of five determining factors: R, an index of rainfall erosiveness that is a product of maximum 30-minute intensity of the rain and its total kinetic energy; K, an index of the susceptibility of a continuously fallowed soil to sheet and rill erosion; SL, a topographic index including both the angle and length of the slope; C, a biological factor expressing the combined influence of vegetal cover and cultural practices; and P, an index showing the effectiveness of supporting erosion control practices, such as contouring.

Knowing the value of rainfall erosivity, soil erodibility, and slope, one can calculate the effectiveness of various erosion control techniques to use if one decides to introduce a cultivation system into an area without exceeding an acceptable erosion rate.

My purpose is to apply the equation to the experimental results obtained in West Africa by the French Office of Research Overseas (ORSTOM) and the French Institute of Applied Research (GERDAT) and define its limit of validity.

Procedure

The results came primarily from 13 stations measuring sheet and rill

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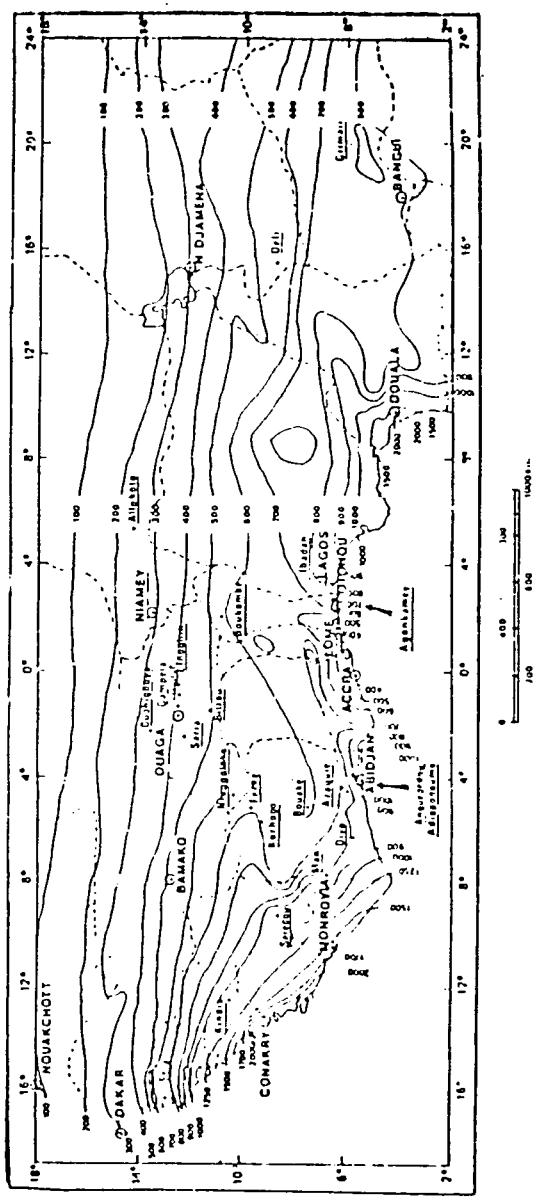

Figure 1. R index in West and Central Africa and location of runoff plots.

Table 1. Variability of index R as a function of the rainfall amount in West Africa.

Rainfall Amount (mm)	R Indexes at Different West African Locations: Abidjan Extreme	Abidjan Ave.	Divo Extreme	Divo Ave.	Bouake Extreme	Bouake Ave.	Korhogo Extreme	Korhogo Ave.	Sarla/Gonse Extreme	Sarla/Gonse Ave.	Allokoto Extreme	Allokoto Ave.
h = 15	0.5 to 8	5	1 to 7	4.5	0.5 to 7	3.7	1.5 to 7	5	2.3 to 6.5	4.7	1.5 to 8	5
h = 30	6 to 24	18	7 to 30	18	4 to 22	16	4 to 26	17	16 to 31	18	6 to 20	18
h = 50	12 to 66	44	20 to 90	48	15 to 80	40	19 to 80	50	30 to 65	48	30 to 65	50
h = 70	32 to 90	78	49 to 108	92	25 to 100	73	31 to 120	83	84 to 104	86	-	-

erosion on about 50 plots of 100 to 5,000 square meters located in five West African countries (Figure 1, Table 4). Climates vary from the dense subequatorial forest in the lower part of Ivory Coast (rain = 2,100 millimeters) to the steppe of the Sahelien plain of the Niger (rain = 500 mm). Aside from the Allokoto station located on a vertisol, all other stations are set up on ferrallitic and ferruginous tropical soils.

Results

The most significant results of experiments are shown here to demonstrate the advantages and the limitations of the universal soil loss equation in West Africa.

Rainfall Erosivity Index, R

On the old eroded surfaces of the African continent, as on the Great Plains and Corn Belt in America where the cultivated slopes are moderate to nearly level, it is the impact energy of raindrops that causes erosion. This impact energy sets into motion the destruction of aggregates while runoff water provides for the transport of detached particles.

On the bare plots of Adiopodoumé, it has been shown (*28*) that the amount of rainfall fails to explain the phenomenon of erosion if one does not simultaneously take into account soil water content before the rainfall and the maximal intensity of the rainfall during a sufficiently long period of time (20 minutes for solids transport and 10 minutes for runoff flow.)

In the Mediterranean and Sahelien zone, Heusch (*12*) and Roose (*24, 34*) estimate that it is the exceptional 50- to 100-year-frequency rain that radically transforms the landscape. On the other hand, the results show that in dry or humid tropical environments the level of erosion depends on the sum of the 10 or 20 most severe rains in a year rather than the exceptional rainfall, taking into account existing well-developed vegetal

cover. All this agrees with the principles contained in the climatic erosivity index of Wischmeier and Smith (*42, 43*), which takes into account the combined effects of amount, maximal intensity, and duration of all significant rain.

Unfortunately, the analysis of rain gauge charts is extremely time-consuming. In an attempt to simplify the method, several authors (*1, 6, 11*) have noticed that excellent linear regressions exist between kinetic energy and the amount of rain; but that the regression between the maximal intensity (I_{30}) and the amount of rain is curvilinear; and the scatter of points is much greater (*4, 26*). Several authors (*6, 7, 11*) have published an equation valid in Upper Volta and in Niger (and probably in all of West Africa) that permits the estimation of the R index as a function of the rainfall amount (H) and its maximum intensity in 30 minutes (I_{30}):

$$R = (0.0158\ H \times I_{30}) - 1.2 \qquad [2]$$

However, the study of the spatial distribution of this index of erosivity, R, poses a major difficulty in Africa due to the small number of stations equipped with a recording rain gauge and the short period during which they have been keeping records. On the other hand, these stations have had at their disposal for the last 20 to 50 years in West Africa a relatively dense network of measuring stations of the amount of daily rainfall, which allows the calculation of representative averages. We therefore have been led to study in detail the connection existing between the amount of daily rainfall and the index of rainfall erosivity, R. The results show that there exist strong variations of R for rainfall of the same amount and that this variation increases with the amount of rainfall (Table 1). On the other hand, the average amounts vary little from one station to another from the lower Ivory Coast as far as the Niger.

In the coastal zone of the lower Ivory Coast, a linear regression exists ($R = 0.577\ H - 5.766$) between this index (R) and the rainfall amount (H) for rainfall of the "June to September monsoon" type. A curvilinear regression exists for high intensity rainfall in the other months. This curvilinear regression is very similar for all the stations studied between Abidjan and Ouagadougou. Based on these regressions, one can transform long series of observations of daily rainfall in order to find satisfactory monthly and yearly averages (5% error) of the rainfall erosivity index and try to map their distribution (*29*). It has been stated, therefore, that a single empirical relationship exists between the yearly average erosivity index (Ram) over 5 to 10 years and the corresponding annual average of rainfall amount (Ham):

$$Ram/Ham = 0.50 \pm 0.05 \qquad [3]$$

This rate has been verified at about 20 rainfall recording stations in the Ivory Coast, Upper Volta, Senegal, Niger, and Tchad, with the exception of stations located around the mountains as well as in the area near the sea. This relationship [3] has permitted us to sketch the distribution of this index in Ivory Coast (*28*), in Upper Volta (*31*) and for the whole of West Africa (*32, 33*). This sketch (Figure 1) is a guide the precision (5%) of which outside of mountainous and coastal zones is sufficient to permit the use of the universal soil loss equation.

Figure 1 shows that the rainfall erosivity is very high in the humid tropical regions and decreases almost parallel to the isorainfall lines between Abidjan (Ham = 2,100 mm; Ram = 1,200) and Ouagadougou (Ham = 830 mm; Ram = 430). This is explained by the correlation between the annual average precipitation in this region, the amount of the 10-year rainfall and the

curves "intensity x duration" (2, 3). Since rainfall is of the same type in all of this zone, it is no longer necessary to include the intensity of the rainfall in addition to its amount in order to evaluate the average rainfall erosivity, as several authors have proposed.

By way of comparison, let us point out that the index varies from 50 to 650 in the United States (*43*), 60 to 300 in Tunisia (*17*), 50 to 300 in Morocco (*14*), 60 to 340 in the South of France (*18*), 500 to 1400 in Ivory Coast (*28*), and 200 to 650 in Upper Volta (*31*).

Soil Erodibility, K

The laboratory tests being insufficient to class soils as a function of their susceptibility to sheet and rill erosion, Wischmeier suggested a study of this factor on reference plots of about 100 square meters, with a 9 percent slope and treated as bare-tilled fallow without the addition of any organic matter for three years. Many soils cultivated in Africa are not represented by slopes of 9 percent. We therefore have adapted this procedure by choosing slopes characteristic of the soils and the landscapes and by correcting the measurements with the aid of the topographic factor (SL). The soil erodibility index therefore is calculated with the following equation:

$$K = \frac{A}{R \times SL \times 2.24} \qquad [4]$$

where A is the erosion in tons per hectare, R is the rainfall erosivity index, SL is the topographic factor, and 2.24 the coefficient necessary to go from metric units (t/ha) to English units (t/acre). In the United States, the erodibility index, K, increases from 0.03 to 0.60 for progressively more erodible soils. Table 2 summarizes what few experimental results exist in West Africa.

Application of the soil erodibility nomograph (*15*) in evaluating the susceptibility of soils to erosion has given satisfactory results for the ferrallitic and ferruginous soils studied, with the exception of soils that were gravelly or covered with rocky debris that acts as a protective mulch. This is very important in tropical and mediterranean regions (*8*, *32*, *33*). At Korhogo, for example, not only is the factor K very low (0.02) but it diminishes proportionately as the gravel concentrates in the upper surface (Table 2).

Table 2. Measured index of erodibility (K) of various soil types used in this study.

Location	Soil Types	Measured K Max.	Min.	Value Used	No. of Measures	Source
Adiopodoume	Low base-saturated ferralitic on argillic-sandy tertiary material	0.17	0.05	0.10	24	(*28*)
Agonkamey	Medium base-saturated ferrallitic on argillic-sandy tertiary material	0.11	0.03	0.10	4	(*38*, *28*)
Bouake	Eroded reworked ferralitic on granite	0.16	0.02	0.12	4	(*1*, *15*)
Korhogo	Impoverished, reworked ferrallitic on granite	0.02	0.01	0.02	6	(*32*)
Gampela	Tropical ferruginous on lateritic pan at 20 cm	0.32	0.05	0.25	5	(*6*)
Saria	Tropical ferruginous on lateritic pan at 50 cm	0.28	0.06	0.25	3	(*29*)
Sefa	Leached tropical ferruginous with stains and concretions	0.17[a]	0.05	0.25[a]	2	(*4*)

[a] The value used for K at Sefa is higher than the maximum value observed because organic matter was plowed into the soil the first year. The effects of this were not overcome in the short term of the experiment.

Table 3. Effect of slope on erosion and runoff as a function of vegetal cover and soil.

	Slope (%)	Erosion (mt/ha/year) Forest	Bare Soil	Cropped Soil	Runoff (%) Forest	Bare Soil	Cropped Soil
Adiopodoume 1965-1972	4.5	-	60	19	-	35	16
Ferrallitic soil on tertiary argillic-sandy materials	7	0.03	138	75	0.14	33	24
Average rainfall = 2100 mm	23	0.1	570	295	0.7	24	24
Séfa (Senegal). Clean cultivated crops from 1955 to 1962. Leached ferruginous tropical soil with stains and concretions			Slope 1.25%	1.50%	2.0%		
Average erosion (in t/ha/year)			5	8.6	12		
Annual average runoff (%)			16	22	30		

		K Estimated by the Nomograph
Various ferrallitic soils	from tertiary sand	0.05 to 0.10
	from granite	0.10 to 0.15
	from schist	0.15 to 0.18
Ferruginous tropical soils from granite		0.20 to 0.30

Two conclusions can be derived from the overall results:

1. The variability of monthly and yearly measurements necessitates going ahead with replications in space and especially in time. The measurements should only be done on tilled fields for over three years without burial of organic matter. Working of the soil eliminates the surface seals formed by the beating action of rain. However, too much cultivation gives soil loss and runoff results lower than the corn or cotton plots. Therefore, one tillage in each rainy season and two or three cultivations and chemical weedings are enough to maintain the soil surface in the desired condition.

2. Ferrallitic soils are very resistant to erosion, and ferruginous tropical soils are clearly less resistant after two or three years of cultivation. This difference is explained by the low permeability of ferruginous

Table 4. Location, vegetal cover, soil, and rainfall at experimental sites.

Location	Years	Agency	Vegetation	Soil	Rainfall	Seasons
Adiopodoumé	1955-75	ORSTOM	Secondary evergreen forest	Impoverished ferrallitic	2100 mm	4
Anguédédou	1966-72	IRCA-ORSTOM	Rubber plantation (parallel to contours)	Impoverished ferrallitic on tertiary argillic-sandy material	2000 mm	4
Azaguié	1966-73	IFAC-ORSTOM	Secondary rain forest, irrigated banana plantation	Reworked ferrallitic on schist	1800 mm	4
Divo	1967-74	IFCC-ORSTOM	Semi-deciduous dense forest	Reworked ferrallitic on granite	1750 mm	4
Bouaké	1960-75	IRAT-ORSTOM	Dense shrub savannah	Eroded ferrallitic on granite	1200 mm	4
Korhogo	1967-75	ORSTOM	Clear shrub savannah	Reworked ferrallitic on granite	1400 mm	2
Ouagadougou	1967-73	IRAT-ORSTOM	Sparse tree savannah	Leached ferruginous on granite	850 mm	2
Sefa (Sénégal)	1954-68	ORSTOM-IRAT	Woodland	Leached ferruginous	1300 mm	2
Cotonou (Benin)	1964-68	ORSTOM	Dense thicket	Impoverished ferrallitic on tertiary argillic-sandy material	1300 mm	4
Boukombe (Benin)	1960-61	ORSTOM	Park savannah	Leached gravel-filled ferruginous on schist	1100 mm	2
Allokoto (Niger)	1966-71	CTFT	Shrub savannah	Vertisol/calcareous	500 mm	2

soils, their tendency to seal, their relatively high content of silt and fine sand, and their very low level of organic matter. It seems, therefore, that the spectacular erosion observed in Africa is due to the extraordinary rainfall erosivity rather than to a particular high erodibility of tropical soils. However, El Swaify (*9*) has shown that in Hawaii the range of erodibility of tropical soils is as great as in the temperate zone.

The Topographic Factor, SL

Most authors agree on the important role that slope (length, shape, and especially steepness) plays in the development of erosion, although erosion can sometimes start on slopes less than 2 percent (*10*). Zings (*46*), summarizing experimentation carried out on the soils of the temperate American regions, showed that soil losses increase exponentially with slope steepness, the average exponent being close to 1.4.

On a ferrallitic soil rich in gravel (alfisol) in Nigeria, Lal (*16*) found that erosion increases with slope according to an exponential curve exponent 1.2 when the soil is bare, but that it is independent of the slope (1 to 15%) if an adequate amount of residue (4 to 6 t/ha) is left on the surface.

On the other hand, Hudson (*13*) in Rhodesia and Roose (*31*) in Ivory Coast found exponents larger than 2 for various tropical soils that are poorly covered. Wischmeier and Smith (*42*) estimated that a second degree fits better than a logarithmic function.

The influence of slope length being variable, participants in a workshop at Purdue University finally adopted, for current usage, the exponent 0.5 to express the influence of slope length on soil losses. The equation linking erosion to slope is written:

$$SL = \frac{\sqrt{\lambda}}{100} (0.76 + 0.53\ s + 0.076\ s^2) \qquad [5]$$

where λ is the slope length in feet and s is the steepness in percent.

At Adiopodoumé, on bare soil and averaged over five years, results similar to those of Wischmeier and Smith's theoretical curve have been found, but these results vary considerably from year to year (*29*). Under cultivation, the results vary greatly as a function of the percent of soil covered and cultural techniques (Table 3). At Séfa in Senegal (*19*), it appears that very slight variations in the slope (0.5%) are sufficient to lead to notable variations of erosion and runoff (Table 3). At Bénin, Willaime and associates (*40, 41*) observed that the influence of slope length on erosion is not constant, nor very important. This uncertain influence of slope length on splash and rill erosion brings back into consideration the effectiveness for African conditions of antierosive techniques, such as terraces, banks, and diversion ditches that are too often blindly used in a variety of climates (*22*).

From a scientific point of view, this topographic factor is surely the weak point of the universal soil loss equation because the influence of slope is not independent of vegetal cover, cultural techniques, soil, and probably of climate (*28, 34*). However, while waiting to have sufficient data available, one can rely either on this topographic index of Wischmeier or an exponential equation of the type ($SL = \lambda^{0.5} \times s^{1.5 \text{ to } 2}$). Both are satisfactory in a large number of practical cases, at least on non-swelling clay soils (*13, 26*).

Vegetal Cover and Cultural Techniques, Factor C

This is by far the most important conditional factor. In fact, as long as the vegetal cover is uninterrupted, whether it is a matter of forests, bush,

Table 5. Erosion (t/ha/year) and runoff (% of annual precipitation) from various slope percentages in West Africa.

Stations	Slope	Erosion: Natural Environment	Erosion: Bare Soil	Erosion: Cropped Soil	Runoff: Natural Environment	Runoff: Bare Soil	Runoff: Cropped Soil	Source
		m t/ha/yr			% of annual rainfall			
Adiopodoume	4.5	-	60	-	-	35 [98]	-	(28), (36)
	7%	0.03	138	0.1 to 90	0.14	33 [95]	0.5 to 30[87]	
	20%	0.1	570	-	0.7[12[a]]	24 [76]	-	
	65%	0.20 to 1	-	-	0.6 to 2.2(16)	-	-	
Anguedudou	29%	-	-	0.6 to 0.3	-	-	0.3 to 0.9	(23)
Azaguie	14%	0.5 to 0.7	-	0.9 to 4.6	0.4 to 4	-	5 to 10	(36)
		Md[b] 0.155	-	Md = 1.83	Md = 1.9	-	Md = 7	
		-	-	-	Max = [31]	-	Max [74]	
Divo	9%	0.5	-		1	-	-	(21)
Bouake	4%	[c]b.0.20	18 to 30	0.1 to 26	b.0.3[16]	15 to 30	0.1 to 26	(27), (1)
		n.b. 0.01			n.b. 0.03			
Korhogo	4%	b. 0.1 to 0.2	3 to 9	-	b. 5[50]	35	-	(32)
Ouagadougou	0.5%	b. 0.15	10 to 20	0.6 to 8	b. 10[illegible]	10 to 60[70]	2 to 32[60]	(6), (30)
		n.b0.01			n.b. 7			
Sefa	1 to 2%	b. 0.02 to 0.50	30 to 55		b. 0.3 to 1.	55	8 to 40	(19), (5)
		n.b. 0.02 to 0.20		2. to 20	n.b. 0.1 to 1.2			
Cotonou	4%	0.3 to 1.2	17 to 27.5 after land clearing	10 to 85	0.1 to 0.9	17	20 to 35	(28), (33)
					[2.5]	[69]	[70]	
Boukombe	3.7	-	-	0.2 to 1.6	-	-	1 to 12	(33), (40)
							Max [75]	
Allokoto	3.0	-	-	0.10 to 18.5	-	-	1 to 22	(7)
							Max [10]	

[a]The numbers in brackets represent the maximum coefficients of flow during a unit rainfall of 10-years frequency.

[b]Md = Median.

[c]The notations b and nb signify "burned" or "not burned."

savannah, and pastureland, or of a simple mulch, erosion and runoff are small despite the erosivity of the rainfall, slope steepness, and soil instability (Tables 4 and 5). The burning of savannah, especially if it is late in the dry season, significantly increases runoff and its solid content (39). But when the soil is totally denuded, erosion becomes catastrophic: Soil losses are multiplied by 100 to 1,000 and the flow by 20 to 50. Under cultivation, erosion is intermediate and varies to a large degree according to the type of crop, the rapidity with which it covers the soil, and the cultural techniques put into use to encourage its growth. Density and earliness of planting, cultivation of the soil, appropriate fertilization, and return of residues play a predominant role.

Factor C of the Wischmeier equation expresses the combined influence of the vegetal cover and cultural techniques on solid transport. It is calculated for each characteristic crop-stage period (5 in the United States and up to 8 in the humid tropical zone with two cultural cycles). Taking into account only the mean annual value, Table 6 presents those values that have been obtained for factor C in West Africa.

The use of factor C is capable of helping to define the cultural techniques best suited to each crop and the rotation to use in order to take into account regional ecological conditions.

Erosion Control Practices, Factor P

Buffer strip cropping and natural or artificial mulching alone could be the subject of small plot studies. These studies could help solve certain problems of soil and water conservation (Table 7).

Buffer Strip Cropping. By alternating on a slope cultivated in parallel

Table 6. The vegetal cover factor and cultural techniques (C Factor) in West Africa.

Cultural Techniques	Annual Average C Factor
Bare continuously fallowed	1
Forest or dense shrub, high mulch crops	0.001
Savannah, prairie in good condition	0.01
Over-grazed savannah or prairie	0.1
Crop cover of slow development or late planting - first year	0.7 to 0.8
Crop cover of rapid development or early planting - first year	0.01 to 0.1
Crop cover of slow development or late planting - second year	0.01 to 0.1
Corn, sorghum, millet (as a function of yield)	0.4 to 0.9
Rice (intensive fertilization)	0.1 to 0.2
Cotton, tobacco (second cycle)	0.5 to 0.7
Peanuts (as a function of yield and the date of planting)	0.4 to 0.8
1st year cassava and yam (as a function of the date of planting)	0.2 to 0.8
Palm tree, coffee, cocoa with crop cover	0.1 to 0.3
Pineapple on contour (as a function of slope) — burned residue	0.2 to 0.5
Pineapple on contour (as a function of slope) — buried residue	0.1 to 0.3
Pineapple and tied-ridging (slope 7%) — Surface residue	0.01
Pineapple and tied-ridging (slope 7%)	0.1

strips (20 to 50 m wide) with narrow strips (2 to 4 m) permanently covered with grass, the landscape is rapidly transformed into a succession of fields of gentle slopes separated by grass-covered embankments. Due to fine roots and to numerous grassy stems, the strips absorb a large part of the flow (10 to 60% at Adiopodoumé) and cause the deposit of eroded soil in the upstream area (70 to 90% at Adiopodoumé) (*22*). Embankments of 50 cm formed naturally in five years following alluvial deposits in buffer strips have been observed at several locations in Ivory Coast. In the Sahelian zone where the grasses have difficulty protecting soils from the first rains, Delwaulle (*7*) has shown on large plots (4,000 m^2) that ridges of earth and low dry stone walls are slightly more effective than grass buffer strips. These methods further permit the determining of a guide from which it will be possible to move from an extensive nomadic agriculture to intensive stabilized cultivation while progressively modifying the topography (*22, 33*).

A straw mulch several centimeters thick is as effective as a dense secondary forest 30 meters high (*29,35*) in absorbing kinetic energy of rainfall and maintaining erosion (0.03 t/ha/year) and runoff (0.5%) within acceptable limits. Given the difficulty of procuring the enormous vegetal quantities necessary to cover large industrial plantings, one must consider either leaving the maximum crop residue on the soil surface or using soil conditioners.

Artificial Mulch. By spraying a thin permeable film of polyvinyl acetate (Curasol supplied by Roechat) at 60 grams per liter per square meter after plowing, soil losses have been reduced from 40 to 90 percent and the flow from 25 to 55 percent of the check. The spraying of this type of permeable plastic, mixed with grass seeds and fertilizers, is a future practice for protection of scalped industrial zones, road embankments, and channels. However, it is still too expensive for ordinary agriculture (*35*).

Cultural practices (maximum soil cover through early and dense planting, use of fertilizer, optimum working of the soil, mulch, plant covering, rotation, etc.) are much more effective in humid tropical zones than mechanical techniques (terraces or diversions) that are costly to build and difficult to maintain. The latter, however, are the practices mentioned most in soil conservation manuals all over the world and most of the time are recommended without preliminary study of adaptation (*22, 25, 28, 29*).

Discussion and Conclusions

More than 500 annual measurements of erosion on experimental plots have been completed in West Africa. This allows us today to evaluate and to put into practice the universal soil loss equation (*44*).

It is well to recall, first, that this equation aims at predicting sheet and rill erosion in hilly areas, excluding mountains, where energy from runoff

Table 7. P factor for conservation practices in West Africa (*7, 28*).

Conservation Practices	P Factor
Tied-ridging	0.20 to 0.10
Antierosive buffer strips from 2 to 4 meters width	0.30 to 0.10
Straw mulch	0.01
Curasol mulch (60 gr/l/m^2)	0.50 to 0.20
2-3 years of temporary grassland	0.5 to 0.1
Reinforced ridges of earth or low dry stone walls (ridge elevation : 80 cm above channel) + tillage + cultivation and balanced fertilization.	0.1

and linear erosion (mountain, stream and river) predominate and where the rainfall has very different characteristics. It neither approaches the problem of flow nor that of transport in solution and neglects the qualitative aspect of eroded materials. But the fertility factors of a large number of tropical soils are found stored in the first 20 centimeters (especially under forest conditions), and sheet erosion selectively removes the organic and mineral colloids as well as the nutritive elements that assure the chemical and water reserve of the soil (*19, 20, 28*).

Secondly, since this empirical equation is based on the statistical analysis of a large number of results, it is important to have numerous replications in space and chiefly in time to evaluate locally the value of the different coefficients to use.

Finally, since the data come from plots of limited area, it is difficult to use these results to predict regional values of sediment transport on large watersheds.

Realizing this, it is necessary to recognize not only the practical utility of this equation on the land to optimize the management of agricultural land, but also an evident scientific interest to define the relative influence of each of the factors under consideration. This equation fulfills its purpose, which is to determine the antierosive techniques to put into practice in each particular case of soil management. On the ancient African continent, its use seems to be perfectly acceptable and justified by a mass of results related to soils and to the slopes most currently cultivated in West Africa.

The erosivity index accurately takes into account the interactions of amount, intensity, and duration of rainfall on solid transport; there could, however, be added to it an "antecedant soil moisture index" expressing this condition before the rain. The analysis of thousands of rain gauge charts has allowed us to present a first approximation of the spatial distribution of the annual mean erosivity index. However, the question must be asked whether it is better to base the erosion control system on the mean erosivity of rain or on the hazard of a 10- or 100-year-frequency rainstorm.

The soil cover resulting from plants (and stones) has an importance that exceeds that of all the other factors determining erosion. Plant architecture as well as tillage practices play only a secondary role once the soil is 90 percent covered; however, the cultural antierosive techniques are very helpful in all the cases where the soil is sparsely covered. Index C allows, in addition, the selection of practices and crops best adapted to local ecological conditions.

Contrary to an opinion widely held among agronomists, ferrallitic soils and, to a lesser degree, ferruginous tropical soils, especially if they are gravelly, seem less erodible than a large number of leached soils of temperate regions. It is the special erosivity of tropical rainfall that leads to the severe erosion damage seen in tropical zones when the soil is bare. The soil erodibility nomograph proposed in 1971 (*45*), which permits the estimation of the index of the resistance of soils to erosion, seems applicable; however, a moderating coefficient should be added to take into account the gravel or rocky debris present in the tilled surface.

If the universal soil loss equation seems to be correctly applied to those clay soils that are predominantly kaolinitic, the most widely occurring and cultivated in West Africa, one must be very cautious where swelling clay soils are concerned (dark brown soils, vertisols, etc.). The work of Heusch's group (*12*) in Morocco demonstrates that the vertisols on the marls of the Rif react very differently.

The topographic factor and in particular the slope length certainly constitutes the weak point of this equation, since it varies with the soil type, cultural technique, and the vegetal cover. But while waiting to gather a

sufficient amount of data under natural or simulated rainfall, it can be used in the majority of cases. Let me note, however, the importance of this caution for the choice of erosion control techniques that are often based on limitations of slope length. Consequently, the anticrosive techniques of the biological type, that is to say cultural practices favoring soil cover, are at the same time the most efficient, the cheapest, the least difficult to use; and they are the best adapted to the conditions of the hills and plains of the ancient African continent.

To be of maximum use in West Africa, data is needed to modify the Wischmeier-Smith equation for soils with swelling clays; for mountainous regions of recent origin, where gully erosion predominates; and for Saharien and Mediterranean zones, where unusually intense rains are important. However, this equation seems to me to be well adapted to the majority of cultivated soils in West Africa and to the moderate slopes on ferrallitic and ferruginous tropical soils in particular.

REFERENCES CITED

1. Bertrand, R. 1967. *Etude de l'érosion hydrique et de la conservation des eaux et du sol en pays Baoulé.* Coll. Tananarive 1967. pp. 1,281-1,295.
2. Brunet-Moret, Y. 1963. *Etude générale des averses exceptionnelles en Afrique Occidentale: République de Haute-Volta.* Rapport ORSTOM, C.I.E.H. 23 pp.
3. Brunet-Moret, Y. 1967. *Etude générale des averses exceptionnelles en Afrique Occidentale.* République de Cote d'Ivoire. Rapport ORSTOM, C.I.E.H. 20 pp.
4. Charreau, C. 1969. *Influence des techniques culturales sur le développement du ruissellement et de l'érosion en Casamance.* VIIe Congrès International du Génie Rural. C.N.R.A., Bambey. 13 pp.
5. Charreau, C. 1972. *Problemes posés par l'utilization agricole des sols tropicaux par les cultures annuelles.* Coll. IITA - IRAT, Ibadan, Nigeria.
6. C.T.F.T./Haute-Volta. 1974. *Rapport de synthèse 1973.* C.T.F.T./ Ministère de l'Agriculture de Haute-Volta, Ouagadougou. 56 pp.
7. Delwaulle, J. C. 1973. *Resultats de six années d'observations sur l'érosion au Niger.* Bois et Forêts des Tropiques 150. pp. 15-37.
8. Dumas, J. 1965. *Rélation entre l'érodibilité des sols et leurs caractéristiques analytiques.* Cah. ORSTOM, sér. Pédol., 3, 4. pp. 307-333.
9. El Swaify, S. A. 1975. *Susceptibility of certain tropical soils to erosion by water.* Coll. I.I.T.A., Ibadan. 12 pp.
10. Fournier, F. 1967. *La recherche en érosion et conservation des sols sur le continent Africain.* Sols africains 12(1): 5-53.
11. Calabert, J., and E. Millogo. 1973. *Indice d'érosion de la pluie en Haute-Volta.* C.T.F.T., Ouagadougou. 34 pp.
12. Heusch, B. 1970. *L'érosion du pré-Rif. Une étude quantitative de l'érosion hydraulique dans les collines marneuses du Pré-Rif occidental.* In *Annales de la Recherche Forestière au Maroc*, 12. pp. 9-176.
13. Hudson, N. W. 1973. *Soil conservation.* BT. Batsford Ltd., London, Eng. 320 pp.
14. Kalman, R. 1967. *Le facteur climatique de l'érosion dans le bassin du SEBOU (Maroc).* Project SEBOU. 32 pp.
15. Kalms, J. M. 1975. *Influence des techniques culturales sur l'érosion et le ruissellement en région Centre de Côte d'Ivoire.* Coll. I.I.T.A., Ibadan. 9 pp.
16. Lal, R. 1975. *Soil management systems and erosion control.* Coll. I.I.T.A., Ibadan. 7 pp.

17. Hasson, J. M. 1971. *L'érosion des sols par l'eau en milieu méditerranéen. Méthode expérimentale pour l'étude des quantités de terre érodée à l'échelle du champ.* Thèse Doct. Ing. Univ. Sciences et Techniques du Languedoc. CNRS n AO 5445. 213 pp.
18. Hasson, J. M., and J. M. Kalms. 1971. *Analyse et synthèse des facteurs de l'érosion sur le bassin versant de la TET à VINCA.* Note 14/71. EDF/Univ., Montpellier. 90 pp.
19. Roose, E. J. 1967. *Dix années de mesures de l'érosion et du ruissellement au Sénégal.* Agron. Trop. 22(2): 123-152.
20. Roose, E. J. 1968. *Erosion en nappe et lessivage oblique dans quelques sols ferrallitiques de Côte d'Ivoire.* Coll. WASA, Abidjan. 15 pp.
21. Roose, E. J., and P. Jadin. 1969. *Erosion, ruissellement et drainage oblique sur un sol à cacao de moyenne Côte d'Ivoire.* ORSTOM/IFCC. Abidjan. 77 pp.
22. Roose, E. J., and R. Bertrand. 1971. *Contribution à l'étude de la méthode des bandes d'arrêt pour lutter contre l'érosion hydrique en Afrique de l'Ouest.* Agron. Trop. 26(11): 1,270-1,283.
23. Roose, E. J. et. al. 1970. *Erosion, ruissellement et lessivage oblique sous une plantation d'hévea de basse Côte d'Ivoire.* ORSTOM-IRCA, Abidjan. 115 pp.
24. Roose, E. J. 1971. *Note technique concernant l'érosion hydrique au Maroc.* Bull. liaison des Ing. Forestiers du Maroc 6: 47-52.
25. Roose, E. J. 1972. *Comparaison des causes de l'érosion et des principes de lutte antiérosive en région tropicale humide, tropicale sèche et méditerranéenne.* Coll. Génie Rural, Florence. pp. 417-441.
26. Roose, E. J. 1972. *Contribution à l'étude de la résistance à l'érosion de quelques sols tropicaux.* Congrès Science Sol Moscou. 11 pp.
27. Roose, E. J., and R. Bertrand. 1972. *Importance relative de l'érosion, du drainage oblique et vertical dans la pédogénèse actuelle d'un sol ferrallitique de moyenne Côte d'Ivoire.* Résultats des campagnes 1967 à 1971. ORSTOM-IRAT, Abidjan. 94 pp.
28. Roose, E. J. 1973. *Dix-sept années de mesures expérimentales de l'érosion et du ruissellement sur un sol ferrallitique sableux de basse Côte d'Ivoire.* Contribution à l'étude de l'érosion hydrique en milieu intertropical. Thèse Doct. Ing., Fac. Sci. Abidjan. 125 pp.
29. Roose, E. J. 1974. *Conséquences hydrologiques des aménagements antiérosifs.* In *XIII Journées de l'Hydraulique, question 3, rapport 10.* 6 pp.
30. Roose, E. J. 1974. *Contribution à l'étude de l'influence de la sécheresse sur l'évolution actuelle de certains sols ferrugineux tropicaux en zone sahélienne.* Rapport ORSTOM, Abidjan. 18 pp.
31. Roose, E. J. J. Arrivets, and J. F. Poulain. 1974. *Etude du ruissellement, du drainage et de l'érosion sur deux sols ferrugineux de la région Centre Haute-Volta.* Bilan de trois années d'observation à la Station de Saria. Rapport ORSTOM/Abidjan - IRAT/Haute-Volta. 83 pp.
32. Roose, E. J. 1975. *Application de l'équation de précision de l'érosion de Wischmeier et Smith en Afrique de l'Ouest.* Coll. I.I.T.A., Ibadan, Nigeria. 22 pp.
33. Roose, E. J. 1975. *Quelques techniques antiérosives appropriées aux régions tropicales.* Coll. I.I.T.A., Ibadan, Nigeria. 7 pp.
34. Roose, E. J. 1975. *Erosion et ruissellement en Afrique de l'Ouest. Vingt années de mesures en petites parcelles expérimentales.* ORSTOM Abidjan. 92 pp.
35. Roose, E. J. 1975. *Natural mulch or chemical conditioner for reducing soil erosion in humid tropical areas.* In *Soil Conditioners.* Spec. Pub. No. 7. Soil Sci. Soc. Am., Madison, Wisc. pp. 131-138.
36. Roose, E. J., and J. Godefroy. 1976. *Pedogenese actuelle d'un sol*

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ferrallitique sur schiste sous forêt et bananeraie fertilisée de basse Côte d'Ivoire. ORSTOM-IRFA. Abidjan sous presse.

37. Seginer, I., J. Morin, and A. Shachori. *Runoff and erosion studies in a mountainous terra-rossa region in Israel.* Symposium de Bari. pp. 79-92.
38. Verney, R., B. Volkoff, and P. Willaime. 1967. *Etude de l'érosion sur "Terres de Barre."* Comparaison sol nu - jachère arbustive, Année 1965. ORSTOM, Cotonou. 14 pp.
39. Verney, R., et P. Willaime. 1965. *Résultats des études de l'érosion sur parcelles expérimentales entreprises au DAHOMEY.* Coll. Karthoum - OUA/STRC No. 98. pp. 43-53.
40. Willaime, P. 1962. *Etudes pédologiques de Boukombé.* ORSTOM, Cotonou. 76 pp.
41. Willaime, P. 1965. *Erosion normale sur Terres de Barre.* ORSTOM, Cotonou. 7 + 9 pp.
42. Wischmeier, W. H., and D. D. Smith. 1960. *A universal soil-loss estimating equation to guide conservation farm planning.* Seventh Int. Cong. Soil Sci., vol. I. pp. 418-425.
43. Wischmeier, W. H. 1962. *Rainfall erosion potential. Geographic and location differences of distribution.* Agr. Eng. 43: 212-215.
44. Wischmeier, W. H., and D. D. Smith. 1965. *Predicting rainfall-erosion losses from cropland east of the Rocky Mountains.* Agr. Handbook 282. U.S. Dept. Agr., Washington, D. C. 47 pp.
45. Wischmeier, W. H., C. B. Johnson, and B. V. Cross. 1971. *A soil erodibility nomograph for farmland and construction sites.* J. Soil and Water Cons. 26(5): 189-192.
46. Zingg, A. W. 1940. *Degree and length of land slope as it affects soil loss and runoff.* Agr. Eng. 21: 59-64.

Skidmore, E.L. 1977. Criteria for assessing wind erosion. FAO Soils Bulletin 34:52-62.

ANNEX VI

CRITERIA FOR ASSESSING WIND EROSION 1/

by E.L. Skidmore

1. INTRODUCTION

Wind erosion is serious in many parts of the world. General areas most susceptible to wind erosion on agricultural land include much of North Africa and the Near East, parts of southern and eastern Asia, Australia and southern South America, and the semi-arid and arid portions of North America (FAO, 1966). In addition, such agricultural areas as the Siberian Plain and others in the USSR are potentially susceptible to wind erosion.

Soil erosion by wind, generally thought to be limited to semi-arid and arid areas, can be a problem wherever: 1) the soil is loose, dry, and reasonably finely divided; 2) the soil surface is smooth and vegetative cover is absent or sparse; 3) the field is large; and 4) the wind is sufficiently strong to move soil. These conditions are likely to prevail in semi-arid and arid areas, where precipitation is inadequate or where the climatic vagaries from season to season or year to year prevent maintaining crops or residue cover on the land; however, they sometimes exist in subhumid and even humid areas.

Wind erosion damages in several ways. It physically removes from the field the most fertile portion of the soil, thereby lowering productivity (Daniel and Langham, 1936; Lyles, 1975). Some eroded soil enters the atmospheric dustload (Hagen and Woodruff, 1973), which obscures visibility, pollutes the air, causes traffic hazards, fouls machinery, and imperils animal and human health. Blowing soil also fills road ditches and irrigation canals, reduces seedling survival and growth, lowers the marketability of many vegetable crops, and increases the susceptibility of plants to disease and to the transmission of some plant diseases.

This paper presents criteria for assessing wind erosion on a regional basis by first assessing it on a field basis. Also, the regional wind erosion hazard can be evaluated based on the erodibility of the soil and meteorological conditions conducive to soil detachment and transport.

2. ASSESSING WIND EROSION ON A FIELD BASIS

Studies to understand the mechanics of the wind erosion process to identify major factors influencing wind erosion, and to develop wind erosion control methods led to the development of a wind erosion equation (Chepil and Woodruff, 1963; Woodruff and Siddoway, 1965). The equation was designed to determine the average potential erosion from a particular field and the field conditions necessary to reduce potential erosion to a specified amount.

1/ Contribution from the Agricultural Research Service, U.S. Department of Agriculture, in cooperation with the Kansas Agricultural Experiment Station. Dept. of Agronomy Contribution No. 1647-a.

It is assumed that the reader is familiar with the wind erosion equation, therefore, only a brief description will be given here. More detail has been given by Chepil and Woodruff, 1963; Woodruff and Siddoway, 1965; Skidmore and Woodruff, 1968; Skidmore et al., 1970; Skidmore, 1976.

The general functional relationship between the dependent variable, E (the potential average annual soil loss in tons per hectare), and the independent variables is: $E = f(I, K, C, L, V)$, where I is a soil erodibility index; K is a soil-ridge roughness factor; C is a climatic factor; L is field length along the prevailing wind erosion direction; and V is equivalent quantity of vegetative cover.

Relations among variables are complex, and a single equation that expresses E as a function of the independent variables has not been devised. The equation was solved in a stepwise procedure involving graphical solutions until a computer solution was developed to simplify the procedure (Fisher and Skidmore, 1970; Skidmore et al., 1970).

The solution of the wind erosion equation gives the amount of erosion expected, in tons/ha/year, from a given agricultural field.

The information needed to assess potential soil loss from a field is: (1) percentage of soil aggregates exceeding 0.84 mm; (2) length and steepness of windward knoll slopes; (3) ridge height and spacing; (4) climatic factor; (5) angle of deviation of prevailing wind erosion direction from right angles to field strip; (6) preponderance of wind erosion forces in prevailing wind erosion direction; (7) height of wind barrier, if any; (8) field width; (9) quantity of vegetative cover; and (10) type of vegetative cover. Information for items 4 and 6 and for determining item 5 can be obtained by month for many USA locations from the literature (Skidmore and Woodruff, 1963). The percentage of soil aggregates exceeding 0.84 mm (item 1) can best be obtained by dry sieving; however, in practice, the percentage is often determined from wind erodibility groups based on soil type or predominant soil textural class (Hayes, 1972). Other factors can be measured in the field or estimated by comparing field conditions with similar field conditions for which the factors have been measured.

3. ASSESSING WIND EROSION ON A COUNTY AND REGIONAL BASIS

The wind erosion equation can be used as a basis for assessing wind erosion on an area, such as a county, larger than an individual field.

In the USA, pertinent data can be obtained from several sources. Annual area cropped and yield data for each major crop are available by county from "Agricultural Statistics", published by state boards of agriculture. Total land area by county is available from the Conservation Needs Inventory; soil data are available from soil surveys; and climatological data are available from the National Climatological Record Center. Using those data and the wind erosion equation, one can estimate potential average annual soil loss for a county or a group of counties.

Consider Ellis County, Kansas, for example. Table 1 gives the major soils in the county, the areal extent of those soils, their approximate erodibility based on soil textural classification, and an estimate of the average annual potential soil loss from each of the soils. For this calculation, it was assumed that the field is wide, smooth and bare of vegetation. The grain yield of major crops was estimated from the average county yield of that crop, multiplied by a factor that compares the estimated capability of a particular soil with other soils in the county to produce a given crop. The straw or stover was estimated from grain yield. On the average, winter wheat produced 1.7 quintals of straw for each quintal of grain. Sorghum and maize produced about equal grain and stover.

Table 1 STRAW RESIDUE PRODUCED ON THE VARIOUS SOILS IN ELLIS COUNTY, KANSAS, AND AMOUNT OF STRAW NEEDED ON THE SOIL TO CONTROL WIND EROSION TO 11.2 t/ha/yr

SOIL	AREA	ERODIBILITY	SOIL LOSS	CONTINUOUS WHEAT: GRAIN YIELD	STRAW PRODUCED	STRAW NEEDED 1/	SURPLUS STRAW 2/
	1000 ha	t/ha/yr	t/ha/yr	q/ha	q/ha	q/ha	q/ha
Anselmo Fine Sandy Loam	0.8	193.0	96.4	16.8	28.5	16.3	-2.1
Armo Loam 1-3SS	2.9	193.0	96.3	16.1	27.4	16.3	-2.6
Armo Loam 3-7SS	3.4	193.0	96.3	14.1	24.0	16.3	-4.3
Armo Loam 3-7SSE	1.0	193.0	96.3	12.1	20.6	16.3	-6.0
Campus-Carlson Complex	4.9	150.0	75.1	12.1	20.6	14.5	-4.2
Corinth Silty Clay Loam 1-3SS	0.2	193.0	96.3	13.4	22.8	16.3	-4.9
Corinth Silty Clay Loam 3-7SS	1.9	193.0	96.3	11.4	19.4	16.3	-6.6
Crete Silty Clay Loam 0-1SS	3.2	193.0	96.3	21.5	36.5	16.3	2.0
Crete Silty Clay Loam 0-1STSV	0.2	193.0	96.3	18.2	30.8	16.3	-0.9
Detroit Silt Loam	1.5	142.0	70.8	20.2	34.3	14.2	2.0
Eltree Silt Loam 0-1SS	0.8	142.0	70.8	22.9	38.8	14.2	5.2
Eltree Silt Loam 1-3SS	2.6	142.0	70.8	21.5	36.6	14.2	4.1
Eltree Silt Loam 3-7SS	2.1	142.0	70.8	20.2	34.3	14.2	3.0
Harney Silt Loam 0-1SS	17.5	142.0	70.8	21.5	36.6	14.2	4.1
Harney Silt Loam 1-3SS	14.6	142.0	70.8	20.2	34.3	14.2	3.0
Harney Silt Loam 3-7SS	4.1	142.0	70.8	17.5	29.7	14.2	0.7
Harney Silty Clay Loam 2-5SSE	8.1	157.0	78.4	16.1	27.4	14.7	-1.0
Harney Silty Clay Loam Complex 3-7SSE	8.9	128.0	63.9	14.8	25.1	13.4	-0.9
Harn.-Carls. Silt Loam 0-1SS	2.0	142.0	70.8	18.2	30.8	14.2	1.2
Harn.-Carls. Silt Loam 1-3SS	18.7	142.0	70.8	17.5	29.7	14.2	0.7
Harn.-Wak. Silt Loam 0-1SS	0.7	142.0	70.8	17.5	29.7	14.2	0.7
Harn.-Wak. Silt Loam 1-3SS	6.5	142.0	70.8	16.8	28.6	14.2	0.1
Holdrege Silt Loam 0-1SS	0.5	142.0	70.8	22.9	38.8	14.2	5.2
Holdrege Silt Loam 1-3SS	1.2	142.0	70.8	21.5	36.6	14.2	4.1
Hord Silt Loam	2.8	142.0	70.8	22.9	38.8	14.2	5.2
McCook Fine Sandy Loam	0.4	143.0	96.3	20.2	34.3	16.3	0.9
McCook Silt Loam	2.3	142.0	70.8	16.8	28.6	14.2	0.1
Mento Silt Loam 0-1SS	0.3	142.0	70.8	15.5	26.3	14.2	-1.1
Mento Silt Loam 1-3SS	8.5	142.0	70.8	13.5	22.8	14.2	-2.8
Mento Silty Clay Loam	1.1	157.0	78.4	12.1	20.6	14.7	-4.4
Mento Soils	6.4	145.0	72.2	10.8	18.3	14.2	-5.1
Munjor Sandy Loam	1.4	193.0	96.3	16.1	27.4	16.3	-2.6
New Cambria Silty Clay	0.7	193.0	96.3	17.5	29.7	16.3	-1.5
Roxbury Silt Loam	6.8	142.0	70.8	22.9	38.8	14.2	5.2
Roxbury Silt Loam Fre. Flded	11.2	142.0	70.8	16.8	28.6	14.2	0.1
Wakeen Silt Loam 1-3SS	2.4	142.0	70.8	14.8	25.1	14.2	-1.7
Wakeen Silt Loam 1-3SSE	0.2	142.0	70.8	10.1	17.1	14.2	-3.7
Wakeen Silt Loam 3-7SS	4.2	142.0	70.8	11.4	19.4	14.2	-4.5
Wann Loam	1.4	142.0	70.8	16.8	28.6	14.2	0.1

1/ Assumes straw is left flat.
2/ Assumes 50% of straw is buried by tillage.

To further assess the erosion in the county, one must know the distribution of the various crops grown on each soil. For example, what portions of the 800-ha Anselmo fine sandy loam are planted to wheat, sorghum, or maize and what portions are in fallow? In addition, what are the dominant tillage and residue management practices on that soil?

But let us consider an area even larger than a county. In the USA a convenient size for assessing wind erosion is the land resource area (LRA), composed of land resource units, each usually several thousand hectares in extent and characterized by a particular pattern of soil (including slope and erosion), climate, water resources, land use, and type of farming. (Major land resource areas consist of geographically associated land resource units; major land resource regions consist of geographically associated major land resource areas, Austin, 1972.)

For example, let consider the counties of LRA 72 in Kansas. This area contains 24 counties with total land area of 5.5×10^6 ha (13.6×10^6 acres) and 3.9×10^6 ha (9.7×10^6 acres) of cropland. The major crops (with area and yield of each) are shown in Table 2. The amount of residue produced per unit land area was estimated from grain yield data, assuming that the residue/grain ratio is 1.0 for maize and sorghum and 1.7 for wheat. Approximately 10% of the wheat planted was not harvested.

Table 2 LAND RESOURCE AREA 72 - 24 KANSAS COUNTIES - 1975-76 YIELD DATA

CROP	AREA	YIELD	RESIDUE 2/	POTENTIAL SOIL LOSS 1/ 1	2	3
	1 000 ha	q/ha	q/ha	t/ha/yr	t/ha/yr	t/ha/yr
Irrigated maize	652	67	67	75	22	16
Sorghum	402	35	35	75	43	31
Hay	137	67	0	0	0	0
Continuous wheat	70	13	23	52	34	25
Fallow wheat	1 273	19	33	40	22	16
Fallow (no crop)	1 273	0	0	75	29	18
Wheat (PHH) 3/	123	0	0	75	45	34
	3 931					

TOTAL LAND INVENTORY AREA: 5 502 700 ha

1/ See text for conditions.
2/ Estimated amount of residue after harvest.
3/ PHH - Planted but not harvested.

Average annual soil loss was estimated by the wind erosion equation (Woodruff and Siddoway, 1965) for three combinations of conditions: 1) Wide field, 1/ bare of residue and with rough surface. 2) Wide field with semi-ridged surface - 1/4 of maize and sorghum residue left standing (30 cm tall), 1/4 flattened on the surface, and the other 1/2 removed; 1/4 of continuous wheat residue on surface plus protective value of growing wheat (seedling and stooling) equivalent to 1/10 residue produced; fallow with 1/5 of the residue produced remaining on surface; wheat (planted, not harvested) with residue equivalent to 1/4 of residue produced in continuous wheat production. 3) Same conditions as 2 except that the field is 200 m (660 ft) wide. The means for the area were 86 and 78, respectively for erodibility I and climatic factor C.

The average annual soil loss for the cropland in the 24-county area, according to the relationship of the wind erosion equation, was 60, 27, and 18 metric tons per hectare for the three levels of assumed management. Most of the non-cropland is rangeland. Assuming that the non-cropland is non-erosive, the average soil loss for the total inventory land area became 43, 20, and 13 t/ha/yr, respectively, for the three levels of management. That corresponds to 588, 274, and 184 million metric tons of soil.

4. ASSESSING EROSION HAZARD FROM BASIC SOIL ERODIBILITY AND CLIMATIC POTENTIAL TO CAUSE EROSION

Two (erodibility and climatic factor) of the five independent variables of the wind erosion equation are basic to the soil and climate of the region and are less alterable by management than are the others. Used together, soil erodibility index and climatic factor show promise for use in assessing wind erosion hazard.

Erodibility Index

Soil erodibility (ease of detachment and transport by wind) is a primary variable affecting wind erosion. From wind tunnel tests, Chepil (1950) determined relative erodibilities of soils (reasonably free from organic residues) as a function of apparent specific gravity and proportions of dry soil aggregates in various sizes. Since then, the non-erodible soil fraction greater than 0.84 mm, as determined by dry sieving, has been used to indicate erodibility of soil by wind. In an early version of the wind erosion equation (Chepil and Woodruff, 1954), erodibility was one of three major factors developed from results obtained principally with a portable wind tunnel (Zingg, 1951a, 1951b; Zingg and Woodruff, 1951).

A dimensionless soil erodibility index, I, (Chepil, 1958; Chepil and Woodruff, 1959) was based on the non-erodible fraction (percentage of clods exceeding 0.84 mm diameter). The quantity of soil eroded in a tunnel is governed by the tunnel's length and other characteristics; therefore, erodibility was expressed on a dimensionless basis so that for a given soil and surface condition, the same relative erodibility value would be obtained regardless of wind tunnel characteristics (Chepil, 1960). The soil erodibility index was expressed as

$$I = X_2/X_1 \qquad (1)$$

where X_1 is quantity eroded from soil containing 60 percent of clods exceeding 0.84 mm, and X_2 is the quantity eroded under the same set of conditions from soil containing any other proportions of clods exceeding 0.84 mm. Soil erodibility index, I, gave a relative measure of erodibility, but actual soil loss by wind was not known.

1/ Wide field means that any further increase in width would not increase erosion hazard. This condition usually occurs for a field between 500 and 1 000 metres.

Therefore, during the severe wind erosion of 1954-56 (1 January through 30 April) 69 fields were studied in western Kansas and eastern Colorado to determine the quantity of soil loss for any field erodibility as determined from various field conditions (Chepil, 1960). The average depth of soil eroded usually was indicated by depth to which wheat crowns and roots were exposed.

Seasonal loss was converted to annual soil loss, and relative field erodibility for each field was determined by procedures previously outlined (Chepil, 1959; Chepil and Woodruff, 1954; Chepil and Woodruff, 1959). The relation between annual soil loss and relative field erodibility was

$$Y = aX^b - 1/cd^X \qquad (2)$$

where Y is annual soil loss (tons per acre); X is dimensionless relative field erodibility; and a, b, c, and d are constants equal to 140, 0.257, 0.01525 and 1.065, respectively. Chepil (1960) recognized that inaccuracies in measuring relatively small annual soil losses from depth of soil removal made conversion of relative field erodibility to annual soil loss by equation 2 highly approximate.

When a field is smooth, bare, wide, unsheltered, and noncrusted, its relative erodibility is equivalent to the soil erodibility index defined by equation (1). When I from equation (1) is substituted for X in equation (2), potential annual soil loss in tons per acre is obtained.

Although percentages of non-erodible fractions vary seasonally with management practices and chemical composition of soil, erodibility is strongly influenced by particle size distribution of the soil. Sands, for example, have insufficient fine material to cement the grains into larger aggregates, and much of the soil mass is single grained and, consequently, very erodible. Further research is needed before we can define erodibility precisely as a function of soil, climate, and management; however, we can reasonably estimate a soil's erodibility based on the textural classification of the soil. Therefore, knowledge of surface soil texture distribution in a region provides a basis for estimating susceptibility of the soil to erosive winds.

Climatic Factor

The climatic factor is an index of the average rate at which soil is moved by wind as influenced by moisture content in surface soil particles and average wind speed. Chepil et al. (1962) proposed a climatic factor to determine average annual soil loss for climatic conditions other than those pertaining when the relationship between wind tunnel and field erodibility was obtained.

The soil moisture term of the climatic factor of the wind erosion equation was developed on the basis that erodibility of a soil varies inversely with the equivalent moisture in surface soil particles (Chepil, 1956). Effective moisture of the surface soil particles was assumed to vary as indicated by the Thornthwaite (1931) P-E index developed to evaluate precipitation effectiveness. The P-E index is the sum of 12 monthly precipitations divided by evaporation ratios.

The soil-moisture term of the climatic factor needs refining. The current procedures assume that effective moisture of the surface soil particles varies with the P-E index, but surface moisture content is transient (Idso et al., 1974; Jackson, 1973; Jackson et al., 1973). Drying rate and dryness of particles are functions of hydraulic soil properties and climatic variables not fully reflected in the P-E index. These relationships need examining and then relating to the wind erosion process.

The windspeed term of the climatic factor is based on the assumption that rate of soil movement is proportional to windspeed cubed. Several researchers (Bagnold, 1943; Chepil, 1945; Zingg, 1953) have reported that when windspeeds exceed those required barely to move the soil, the soil-movement rate is directly proportional to friction velocity cubed. Over a specified surface, windspeed and friction velocity are proportional.

The long-term average windspeed and soil moisture index at Garden City, Kansas, was the reference for the climatic factor. It was expressed as

$$C = 100\ u^3/2.9\ (P-E)^2$$

where u is the corrected mean annual windspeed for a standard height of 30 feet, P-E is an index of equivalent moisture in surface soil particles, and 2.9 is the approximate average value of $u^3/(P-E)^2$ for Garden City, Kansas.

Monthly windspeeds are used in lieu of annual windspeeds to determine monthly C values for calculating erosion when plant damage of certain periods of the year is the major interest (Woodruff and Armbrust, 1968). Climatic-factor maps have been prepared for the major wind erosion areas of the USA (Skidmore and Woodruff, 1968). Figures 1 and 2 show that in 1975-76 in the Great Plains the climatic factor and wind erosion damage to cropland were similar.

The product of an appropriate climatic factor and soil erodibility index indicate intensity of wind erosion hazard (WEH) for wide, smooth fields bare of vegetation. Suppose the land in a region is divided into n erodibility groups, each with area A_i and associated erodibility index I_i and climatic factor C_i. Then the mean wind erosion hazard for that region would be

$$WEH = \sum_{i=1}^{n} A_i I_i C_i \Big/ \sum_{i=1}^{n} A_i .$$

As other data such as amount and kind of vegetative cover become available, they can be included in the calculation. Also, because I and C vary seasonally and yearly, it may be desirable to calculate probabilities.

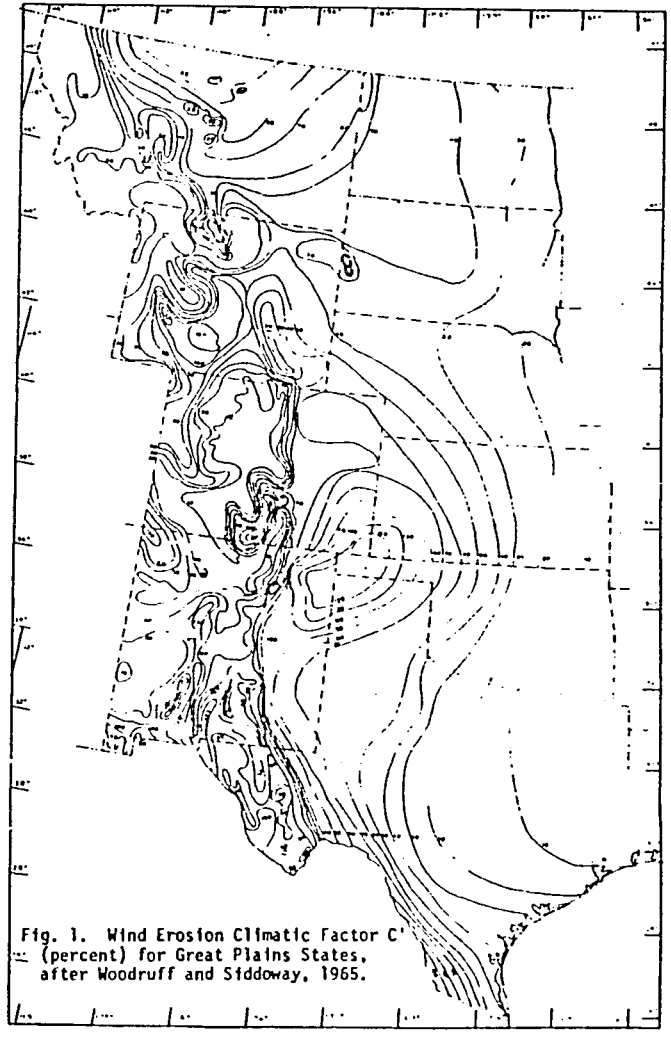

Fig. 1. Wind Erosion Climatic Factor C' (percent) for Great Plains States, after Woodruff and Siddoway, 1965.

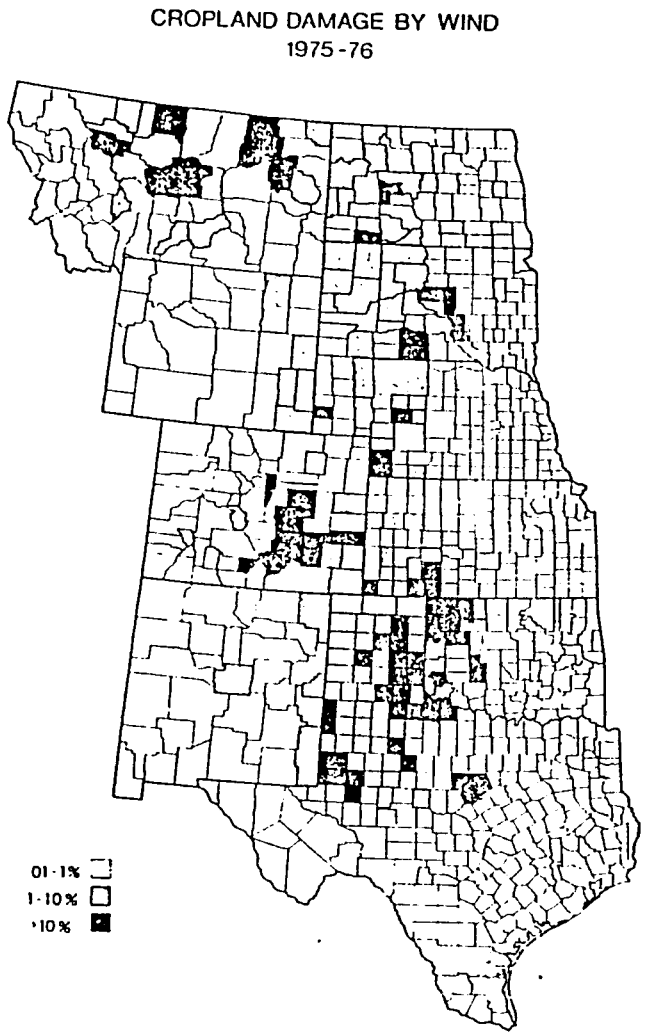

Fig. 2. Percentage of cropland damaged by wind erosion, summarized from data reported by U.S. Dept. of Agriculture, Soil Conservation Service.

REFERENCES

Austin, M.E. 1972 Land resource regions and major land resource areas of the United States. Agriculture Handbook 296, USDA Soil Conservation Service, 82 p.

Bagnold, R.A. 1943 The physics of blown sand and desert dunes. William Morrow, New York, N.Y., 265 p.

Chepil, W.S. 1945 Dynamics of wind erosion: I. Nature of movement of soil by wind. Soil Science 60:305-320.

Chepil, W.S. 1950 Properties of soil which influence wind erosion: II. Dry aggregate structure as an index of erodibility. Soil Science 69:403-414.

Chepil, W.S. 1956 Influence of moisture on erodibility of soil by wind. Soil Sci. Soc. Amer. Proc. 20:288-292.

Chepil, W.S. 1958 Soil conditions that influence wind erosion. USDA Tech. Bul. No. 1185, 40 p.

Chepil, W.S. 1959 Wind erodibility of farm fields. J. Soil Water Conserv. 14:214-219.

Chepil, W.S. 1960 Conversion of relative field erodibility to annual soil loss by wind. Soil Sci. Soc. Amer. Proc. 24:143-145.

Chepil, W.S., Siddoway, F.H. and Armbrust, D.V. 1962 Climatic factor for estimating wind erodibility of farm fields. J. Soil Water Conserv. 17:162-165.

Chepil, W.S. and Woodruff, N.P. 1954 Estimations of wind erodibility of field surfaces. J. Soil Water Conserv. 9:257-265, 285.

Chepil, W.S. and Woodruff, N.P. 1959 Estimations of wind erodibility of farm fields. USDA Prod. Res. Rpt. No. 25, 21 p.

Chepil, W.S. and Woodruff, N.P. 1963 The physics of wind erosion and its control. Advances in Agron. 15:211-302.

Daniel, H.A. and Langham, W.H. 1936 The effect of wind erosion and cultivation on the total nitrogen and organic matter content of soils in the Southern High Plains. J. Amer. Soc. Agron. 28:589-596.

Fisher, P.S. and Skidmore, E.L. 1970 WEIOS: A Fortran IV program to solve the wind erosion equation. USDA, ARS 41-174, 13 p.

Food and Agricultural Organization of the United Nations. 1960 Soil erosion by wind and measures for its control on agricultural lands. Agric. Development Paper 71, FAO, Rome.

Hagen, L.J. and Woodruff, N.P. 1973 Air pollution from duststorms in the Great Plains. Atm. Environ. 7:323-332.

Hayes, W.A. 1972 Designing wind erosion control systems in the Midwest Region. NTSC Technical Note, Agronomy-LI-9.

136

Idso, S.B., Jackson, R.D., Reginato, R.J., Kimball, B.A. and Nakayama, F.S.
1975 The dependence of bare soil albedo on soil water content. Appl. Meteorol. 14:109-113.

Jackson, R.D. Diurnal changes in soil water content during drying. In:
1973 Field Soil Water Regime. R.R. Bruce (Ed.), Soil Sci. Soc. Amer. Special Pub. No. 5.

Jackson, R.D., Kimball, B.A., Reginato, R.J. and Nakayama, F.S. Diurnal
1973 soil-water evaporation: Time-depth-flux patterns. Soil Sci. Amer. Proc. 37:505-509.

Lyles, L. Tensible effects of wind erosion on soil productivity. J. Soil
1975 Water Conserv. 30:279-283.

Skidmore, E.L. A wind erosion equation: development, application, and
1976 limitations. ERDA Symposium Series 38, Atmosphere-Surface Exchange of Particulate and Gaseous Pollutants (1974), pp. 452-456.

Skidmore, E.L., Fisher, P.S. and Woodruff, N.P. Wind erosion equation:
1973 computer solution and application. Soil Sci. Soc. Amer. Proc. 34:931-935.

Skidmore, E.L. and Woodruff, N.P. Wind erosion forces in the United States
1968 and their use in predicting soil loss. USDA, ARS, Agr. Handbook No. 346, 42 p.

Thornthwaite, C.W. Climates of North America according to a new classifi-
1931 cation. Geog. Rev. 25:633-655.

Woodruff, N.P. and Armbrust, D.V. A monthly climatic factor for the wind
1968 erosion equation. J. Soil Water Conserv. 23:103-104.

Woodruff, N.P. and Siddoway, F.H. A wind erosion equation. Soil Sci.
1965 Soc. Amer. Proc. 29:602-608.

Zingg, A.W. Evaluation of erodibility of field surfaces with a portable
1951a wind tunnel. Soil Sci. Soc. Amer. Proc. 15:11-17.

Zingg, A.W. A portable wind tunnel and dust collector developed to evaluate
1951b the erodibility of field surfaces. Agron. J. 43:189-191.

Zingg, A.W. Wind tunnel studies of the movement of sedimentary materials.
1953 In: Proc. Fifth Hydraulic Conference, Iowa Institute of Hydraulics Res. bul. 34, pp. 111-135, John Wiley, New York, N.Y.

Zingg, A.W. and Woodruff, N.P. Calibration of a portable wind tunnel for
1951 the simple determination of roughness and drag on field surfaces. Agron. J. 43:191-193.

(37)

Fournier, F. 1967. Research on soil erosion and soil conservation in Africa. Sols Africains 12:53-96.

RESEARCH ON SOIL EROSION AND SOIL CONSERVATION IN AFRICA

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* This article will be used as one of the bases for a Soils Conservation Manual which the French State Secretariat for Co-operation proposes to publish.

INTRODUCTION

Tropical regions and sub-tropical regions with winter rains (Mediterranean-type) climate are amongst the regions of the world where the problem of soil erosion is most acute. Africa is no exception to that rule and for some fifteen years the damage suffered by its soil has been a subject of serious concern.

" Senegal is sounding the alarm. Whole regions are being exhausted for a very long time. In other parts (. . . of Africa) good land is becoming rare and is being fought over, even between neighbouring villages. Such occurrences are still localised, but they are warnings which cannot be ignored.

Agriculture must not be practised on a day-to-day basis. The land becomes exhausted more quickly than one would think and restoration is extremely slow. Moreover, the soils of Africa are poor ; their reserves are so limited that they are hardly worthy of the name.

In view of the importance of agricultural production in supplying food for the Africans and as a source of wealth, special attention should be devoted to soil conservation, taking account of the need to cultivate the land. It is not merely a question of protecting certain regions, but also of developing a rational method of farming the land to ensure that it retains its production potential."

Research and production organisations have therefore started to study this problem. In addition, it was decided in 1954 that systematic measurement of erosion was essential in addition to purely agronomical research.

The assessment of soil loss and the simultaneous study of the phenomena causing or favouring it can provide accurate information on the effects of such phenomena. Such knowledge is important because these effects must be counteracted.

The assessment of soil loss under numerous environmental conditions, natural or created by man, makes it possible to measure the effect of these conditions on erosion and soil conservation. It may in particular lead to conclusions on the conservation value of plants or cultivation techniques.

For that reason Soil Conservation Research Stations have been established in Africa since 1954. Their functions include :

(*a*) measuring run-off and soil loss resulting from water attacking the soil ;
(*b*) studying the factors involved in run-off and erosion ;
(*c*) measuring the conservation value of plants and cultivation techniques and systems.

The method of investigation used to carry out these functions is that of **experimental plots.**

An experimental plot consists of two parts : an experimental field several square yards in area, acting as a hydrological basin, in which it is possible to create the environment to be studied, and a collection system situated at a lower level where the water and soil leaving the field after each rainstorm can be collected.

The figures thus obtained have the following significance :

To be complete, an assessment of erosion must comprise three types of measurement :

(1) Measurement of the quantity of soil displaced by raindrops when they hit the ground and exert a mechanical action on it.

(2) Measurement of the quantity of soil lost from the field.

(3) Measurement of the quantity of soil finally lost by the river basins of various sizes encompassing the sites at which the above measurements are taken.

Only the last estimate can provide information on the extent of overall erosion occurring throughout a given region, since it comprises the sum of all the effects in all parts of that region.

It would be erroneous to believe that a measurement made at experimental field level could have the same meaning. An experimental field of a few hundred square yards in area is extremely limited in comparison with the area of the geographical region in which it is situated. It forms an environment defined with great precision. However, the natural environment is essentially variable and the phenomena occurring there are affected accordingly. Hence the absolute values obtained at one point cannot be applied to all the points of a given region.

However, the figures obtained from a study of experimental fields are of great interest when considered individually as they form indices of the possible extent of a phenomenon in a specific region and under given conditions.

Above all, they are of vital interest and have full significance when one factor in soil erosion is varied in a series of experimental fields, while all the others are maintained unchanged. The critical values of the varied factor can be ascertained from subsequent comparisons, and as a result conclusions on soil conservation can be drawn and a rational development plan prepared which allows for the conservation of the land cultivated.

With the increased need for rapid data, the measurement of run-off and erosion caused by artificial rain is also used in addition to measurements on experimental plots, but the principles of the methods have remained the same.

The reader will find here the results of the research carried out and the lessons to be learned from them. Both are as yet incomplete, but they already make a contribution to soil conservation in Africa.

* * *

PART I

FACTORS INVOLVED IN SOIL EROSION BY WATER

Atmospheric precipitation is the factor which causes soil erosion by water. The type of soil, the slope, the vegetation and man are a group of factors affecting that phenomenon.

Anyone travelling through Africa soon realises that in many regions the prevailing conditions make the natural environment highly susceptible to attack by water. Such an environment offers little resistance to the action of the agent causing erosion, viz. rain.

A.—FACTORS AFFECTING SOIL EROSION BY WATER

I. Type of Soil

All the research work done so far has not enabled any conclusions to be drawn on the erodibility of the soils of the African continent, whatever their category. Long series of measurements of run-off and erosion on bare soil would be necessary for that. The following individual results have been obtained.

(1) Evolution of Structural Stability and Permeability in a Savannah Region

Tropical ferruginous soils, often predominantly sandy in composition, have a characteristic which makes them particularly susceptible to erosion, viz. the great instability of their structure as soon as they are cultivated. This has appeared very clearly at the Sefa station (Senegal) during the mechanised cultivation of groundnuts (Table I).

Structural stability has been assessed by using Henin's " instability index " (Is), the factors of which are:

—the average percentage of stable aggregates (arithmetical mean of three percentages of water-stable aggregates, viz. stable without pretreatment; stable after pretreatment with alcohol; stable after pretreatment with benzene).

—the dispersed " clay plus silt " fraction.

—the " coarse sand " fraction.

$$Is = \frac{\text{" clay plus silt " dispersion}}{\text{stable aggregates} - 0{\cdot}9 \text{ coarse sand}}$$

each term being expressed as a percentage. When $\log_{10} Is = 1$, the stability is considered to be good.

The coefficient K is from Darcy's law and constitutes a test of permeability on a sample of worked soil.

The results show that the structural stability of virgin soils at Sefa is satisfactory, as is permeability (3–5 cm./hour).

Table I.—Study of the structural stability and permeability of the upper horizon of tropical ferruginous soils at the Sefa station (Senegal)

Stable aggregates (average %)	Clay plus silt dispersion (%)	Is	K (cm/hour)
Under forest or forested border of fields under mechanised cultivation (5 samples)			
46·3	9	0·57	3·07
44·7	9	0·52	3·68
43·3	7	0·40	3·11
45·3	7·5	0·43	4·70
44·3	8·5	0·50	3·70
After one year of cropping to groundnut (3 samples)			
40·6	7·5	0·74	2·40
37·9	8	0·85	3·07
40·3	8·5	0·88	2·09
After two years of cropping to groundnut (1 sample)			
40·9	11·5	1·21	2·5
After six years of cropping to groundnut (*a*)—experimental field; (*b*)—large-scale mechanisation			
(*a*) 37·2	13·5	1·45	1·88
(*b*) 39·3	18	1·58	2·24
(*b*) 38·9	20	1·77	2·66
(*b*) 42·9	16·5	1·42	2·41
(*b*) 37·1	15·5	1·58	2·21

From the first year that groundnuts are grown, it is clear that there is a decrease in structural stability though it remains adequate: Is increases from 0·43–0·57 to 0·74–0·88. The percentage of stable aggregates also decreases to about 40%. Permeability suddenly becomes fairly low since the values of K for the three samples drop to between 2 and 3 cm./hour.

After two years of groundnut crops, it is clear that the situation worsens. The dispersed clay plus silt fraction amounts to 11·5% for the sample analysed. That means that 57 to 76% of the fine particles in the upper soil horizon are dispersed. Is is 1·21, i.e. the structure is consequently becoming increasingly instable. Permeability is fairly low, 2·5 cm./hour, but it was already low after the first year of cropping.

After six years of groundnut crops, the percentage of stable aggregates is almost always less than 40%. The dispersed clay plus silt fraction is between 13·5 and 20%. As mechanical analysis shows that on the surface the soil studied consists of 15 to 20% particles of less than 20μ, it is clear that almost all the fine particles are dispersed. They no longer have any aggregating

power. Structural instability is evident, viz. Is is between 1·42 and 1·77.

This group of results illustrates the rapidity with which soil structure can deteriorate in a tropical environment.

After six years of continuous groundnut cultivation on tropical ferruginous soil, the dispersion of almost all the fine particles and structural instability are certain to ensue. In reality, the process of reduction of structural stability begins from the first year of cropping and permeability diminishes rapidly. After two years, the soil structure already shows an instability almost equal to that found after six years. Therefore in only two years the structure of the soil deteriorates, the permeability decreases and the risk of run-off and erosion increases.

(2) Influence of Soil Properties

The above example shows the importance of the cohesion and stability of soil aggregates as factors affecting run-off and erosion. The more porous a soil remains, i.e. the more spaces penetrable by water in it, the higher is the speed of infiltration through it. Under such conditions, rain must have a very strong action before run-off occurs. However, if soil structure and porosity are poor, infiltration speed is low and run-off occurs easily.

The state of the upper part of the soil is not the only factor to be considered. The permeability of the subsoil is also of importance. If it is poor, the water is arrested in its passage through the soil and the upper part becomes saturated thereby facilitating run-off.

Any factor affecting the cohesion and stability of soil aggregates consequently becomes a factor affecting the phenomena studied here. Particular attention should be paid to the role of the humic and argillaceous colloids which cement sandy and silty particles. That is not their only role, for they also govern the soil's water retention capacity. Chemical composition of the soil also plays a part, for example the nature of the bases in the complex may determine its flocculation (calcium, magnesium) or dispersion (sodium).

Particle size distribution of the soil is also a factor which affects its liability to erosion. There have as yet been no precise studies of this subject in Africa. Hudson expressed certain opinions based on his research work. He is of the opinion that the extent of run-off determines the amount of erosion on sandy soils because their structural stability is low. On the other hand, the intensity of rainfall governs erosion on clay soils, as run-off is always sufficient to carry away detached material. Hudson also considers that sandy soils first lose the colloidal fraction they contain when erosion starts, then the greater the quantity of colloids they have lost, the more sand is washed away. On clay soils, however, the composition of the eroded material is closer to that of the soil left in position and erosion is more constant. In conclusion, Hudson recommends much shorter crop rotations on sandy soils than on clay soils.

Some researchers do not agree with this theory. Nevertheless, the

importance of the level of action of rain in the susceptibility of soils to attack by water should be specified. Sandy soils, with a mono-particle structure, definitely have a very high degree of detachability. Clay soils, with a better structure, have a higher resistance to attack by water, but only provided the level of action of the rain has not caused dispersion. Once that threshold is crossed, they become at least as susceptible to erosion as sandy soils, if not even more so.

II. Slope

Throughout the world, slope affects soil erosion. But the research carried out on experimental plots in tropical Africa has led to the following two conclusions regarding that zone.

(1) The first is that intense erosion occurs when the soil is poorly protected, whatever the gradient of the slope and however slight it may be. Table II shows this.

Table II.—Soil losses recorded in West Africa on different slope gradients in the absence of soil conservation

Station	Crop	Gradient of slope %	Erosion t/sq. km./annum	Period of study
Seredou (Guinea) . .	Cinchona	25	2,448	June 1955/ June 1956
Kindia (Guinea). . .	Citrus fruits (on bare soil)	6	1,787	1956
Adiopodoumé (Ivory Coast) .	Bare soil	7	11,770	1956
Sefa (Senegal) . . .	Groundnuts	2	1,728	1954
	Groundnuts	1	1,494	1955

This shows clearly that a steep gradient corresponds to severe erosion, but that under the eco-climatological conditions considered here, the erosion is just as severe on very slight slopes of 1–2%.

The severity of erosion on these slopes is indicated by a comparison of the results of measurements made at Sefa (Senegal) and at Watkinsville (Georgia, U.S.A.) under completely similar conditions, viz. mechanised cultivation of groundnuts on tropical ferruginous soil, equally aggressive climate, experimental plots of the same dimensions. In the latter place, soil loss of 1,321 t./sq. km./annum on a slope of 3% was considered severe. At Sefa, even more severe erosion on a slope of 2% was recorded in 1954, viz. 1,728 t./sq. km./annum and in 1955, on a slope of only 1%, the erosion measured was 1,494 t./sq. km./annum, i.e. higher than that recorded at Watkinsville with a slope three times as steep. At Watkinsville, a soil loss of 707 t./sq. km./annum under green manure (*Sericea lespedeza*) does not occur until slopes are 7 to 11%. A similar value (698 t./sq. km. annum is reached at Sefa with only a 1% slope (sorghum).

These comparisons show the possible extent of soil erosion in tropical

Africa and indicate that as the action of the rain is so powerful slope plays only a minor role in triggering off the phenomenon. However, slope has a marked effect on the development of erosion. That is a second conclusion also based on the measurements made at Sefa (Senegal).

(2) In 1955, 1956 and 1957 run-off and soil loss were measured on two experimental fields providing absolutely identical environments each year, but with one difference, viz. the slope (see Table III).

Table III.—Soil losses recorded at Sefa (Senegal) on two slopes of 1 and 1·5%

Year	Crop	P (mm.)	Slope 1%		Slope 1·5%	
			R (%)	E (t/sq. km.)	R (%)	E (t/sq. km.)
1955 . .	Sorghum	1,340	11·2	698	26·1	1,420
1956 . .	Groundnuts	1,148	9·1	305	16·8	433
1957 . .	Rice	1,004	21·5	644	20·5	954

P = annual rainfall ; R = annual run-off as % of P ;
E = erosion in tons per sq. km.

Table III shows the marked effect of an increase of as little as + 0·5% on soil loss. This indicates that the slope must have a powerful effect on the extent of erosion in tropical Africa. The existence of severe erosion on very slight slopes, however, indicates that the presence of a slope is not necessary to trigger off erosion, i.e. the action of the rain is sufficient.

III. Vegetation

There is no longer any need to prove the vital importance of vegetation in the combat between water and soil. Research on biological methods of controlling erosion by water are continually emphasising its contribution towards conservation when used rationally by man. Table IV simply presents some figures relating to the main forms of tropical vegetation, viz. forest, savannah, grassland, and indicates their degree of intervention.

Table IV.—Soil losses under various forms of vegetation
Adiopodoumé (Ivory Coast)—(slope : 7%)

Year	P mm.		Secondary forest	Bare soil	Green manures Bengal hemp *Flemingia*	Manioc	Natural fallow
1956 .	1,939	R % E (t/ha)	2·1 2·4	17·4 117·7	12·6 45·2	16·4 92·8	
1957 .	2,383	E t/ha	0·03	104·5	0·1	28·7	
1961 .	2,289	E t/ha	0·02	143·2	0·4		0·46

Sefa (Senegal)—(Slope : 2%)

Year	P mm.		Forest	Bare soil	Green manure : sorghum	Ground-nuts	Natural fallow
1955 .	1,395	R % E t/ha	0·005 0·02	49·3 27·13	18·7 10·6	17·8 14·9	5·6
1961 .	1,231	R % E t/ha	1·2 0·22	50·2 54·5	40·4 8·6	44·6 5·2	14·6 9·8

Lake Alaotra (Madagascar)

Year	P mm.		Degraded *Aristida* grassland 20% cover	Regenerated *Aristida* grassland 100% cover	Eucalyptus re-afforestation 6 years plus *Aristida*	Crops
1959–60	977·5	R % E t/ha Slope %	29 12 20	6·9 0·026 36	3·7 0·025 15	15·4 59 7

Kindia (Guinea)—(Slope : 7%)

Year	P mm.		Citrus on bare soil	Citrus plus *Pueraria*	Citrus plus *Dolichos lablab*	Pine-apple
1956 .		R % E t/ha	9·4 17·9	2·1 3·1	2·2 5·6	1·6 2·05
1957 .		R % E t/ha	9 30·7	2·8 4·25	4·2 9·3	4·4 0·9
1958 .		R % E t/ha	8·1	2·4 0·75	2·4 1·2	4·2 1·15
Average		R % E t/ha	9·2 18·9	2·4 2·7	2·9 5·4	3·4 1·4

Forest, whether dry (Sefa) or humid (Adiopodoumé), is always the best form of vegetation for conservation of both soil and water. The undergrowth plays a vital role, viz. it holds and protects the soil while the larger trees absorb the kinetic energy of the raindrops.

Grassland, once established, appears to hold and protect the soil as well as forest plus undergrowth, but its protective role is more marked as its coverage of the soil, is denser. The experiments carried out at Lake Alaotra in Madagascar are significant in this respect. Table V supplements Table IV.

Whatever the effect of slope, erosion decreases (and almost disappears) when the unprotected area of soil surface is reduced. Erosion is almost nil when soil is 100% covered.

Fallow contributes towards soil conservation, but the extent depends on its type and density.

Table V.—Run-off and soil losses under diverse *Aristida* and *Cynodon* grasslands providing different degrees of cover. (Lake Alaotra, Madagascar, 1959-60)

Plant	% of soil covered	Slope %	R %	E tons/hectare
Aristida . . .	20	20	29	12
Aristida . . .	20	24	24	12
Aristida . . .	40-60	35	45	4
Aristida . . .	100	36	6·9	0·025
Cynodon . . .	100	36	4	0·025

Crops permit erosion, but the erosion is generally less severe than that on soil kept without any plant cover. The less attention paid to soil conservation in the cultivation techniques used, the more severe the erosion.

An experiment carried out in Southern Rhodesia (Henderson Research Institute, Mazoe), shows how important the effect of cover can be on cultivated soil. Continuous maize cropping with inadequate fertilisation has caused an average rate of erosion of 18 t./ha/annum together with an average rate of run-off of 14% of annual rainfall. With intensive fertilisation, those figures were reduced to 6·3 t. ha./annum and 8% respectively simply because the maize foliage developed better and therefore provided better soil cover.

The main effect of covering the soil with vegetation is to control the kinetic energy of raindrops and prevent them from beating against the soil, with all the consequences resulting therefrom, viz. maintenance of the soil structure on the surface, better infiltration, reduced run-off, etc. This is shown by an experiment also carried out in Southern Rhodesia (Henderson Research Institute, Mazoe). Under gauze erected 10 cm. above a plot of bare soil, the average annual erosion observed from 1953 to 1956 was 2·4 t./ha, approximately the same as that observed under dense *Digitaria* (2·8 t./ha). During the same period, a bare plot without gauze lost 269·8 t./ha/annum. The gauze did not prevent the water from reaching the soil, but the drops only fell from a height of 10 cm. which cancelled their original kinetic energy.

IV. Man

The fact that man draws his subsistence from the soil affects erosion which increases when the soil is used irrationally.

The theory that there is no natural environmental equilibrium in tropical or Mediterranean zones is incorrect. The degree of equilibrium is often low, however, particularly on light soils, and consequently careful consideration must be given to any human intervention.

The **mechanisation of agriculture,** in particular, poses very serious problems, since if it is too intensive and badly executed it can easily destroy a delicate equilibrium. The example of Sefa is a good illustration of this danger.

The Compagnie Générale des Oléagineux Tropicaux had established an agricultural sector in Casamance (Senegal) for the mechanised cultivation of groundnuts on tropical ferruginous soils composed of 80–85% sand and 15–20% clay and silt. First of all it was necessary to use machinery to clear the forest and establish plantations just over half a mile long by about 270 yards wide, separated by strips of forest left to form wind-breaks about 60 feet wide. Clearing was carried out in five stages:

(*a*) Cutting down the forest in the rainy season by means of a chain drawn by two bulldozers.
(*b*) Clearing felled trees away from the plot in the dry season.
(*c*) Uprooting of large stumps.
(*d*) Systematic root-cutting of the whole surface, i.e. passage with a straight blade to a depth of 8 inches.
(*e*) Raking following by levelling.

The uprooting and rootcutting operations carried out to remove as many roots as possible are compulsory if mechanised cultivation is to be practised subsequently.

All these operations, particularly those carried out in the dry season, lead to considerable deterioration of the soil. The surface is powdered by the repeated passage of caterpillar tracks and tractors, the haulage of trees and the raking of the leveller. The extensive and interwoven mass of root hairs which forms a sort of " reinforcing " structure in horizon A of forest soil is removed, or rather torn up. As a result of these interventions the structure of the topsoil is very degraded by the time it is put under cultivation.

The soil is prepared mechanically after the first rains. At that time cultivation with disk tillers is effective, rapid and re-forms a cloddy structure. Unfortunately the macrostructure thus obtained is unstable and is affected by the many subsequent mechanised operations. These operations, both for groundnut and rice crops, consist of:

(*a*) Preliminary ploughing with a 16-disk plough.
(*b*) Manure spreading.
(*c*) Second ploughing with a 30-disk plough.
(*d*) Harrowing followed by sowing.
(*e*) Two or three cultivations and, for ground nuts, ridging and mechanical lifting at harvest time.

A crop of green manure is sown after the ground has been ploughed once and is turned in before the end of the rains to allow the green vegetation to decompose.

All these operations favour erosion because:

(*a*) The first ploughing operations which disturb the soil to a depth of 10–12 cm. have the disadvantage of being carried out in June, at the time of the highly erosive tornadoes at the beginning of the rainy season.

(*b*) The work of turning in the green manure to a depth of 20 cm. is carried out in August, generally a very rainy month.

(*c*) The hoeing and hoeing-ridging operations provide parallel and continuous drainage channels for the water which soon lead to the formation of rills.

(*d*) The number of passages with machinery is considerable, viz. nine passages in the case of groundnuts and six in the case of rice.

The obvious conclusion is that after clearing, which already diminishes soil cohesion and causes preliminary degradation of structure, the mechanical operations, repeated each year, reduce the resistance of the soil.

Stubble-ploughing and ploughing take place at a time when the rains are most erosive. The frequent passage of cultivation machinery subsequent to ploughing is bound to increase erosion due to excessive tillage of the surface soil. The effect of this has been measured at Sefa and the figures obtained clearly show the danger of badly planned mechanised cultivation (Table VI).

Table VI.—Erosion from peasant cultivation (1) and mechanised cultivation (2) during a four-year crop rotation (Sefa, Casamance, Senegal)

	1954 Groundnuts	1955 (1) Fallow (2) Rice	1956 Groundnuts	1957 Rice	1961 Rice
Rainfall mm.	1,303	1,395	1,265	970	1,231
Run-off % (1)	33·3	19·9	22·7	22·4	37·4
(2)	47	49·3	39·5	25·3	50·2
Erosion t/sq. km. (1)	1,257	560	577	695	2,930
(2)	1,728	2,713	1,075	975	5,450

Run-off was higher under mechanised cultivation because of deep compaction of the soil caused by the repeated passage of machinery leading to quicker waterlogging of the surface horizon. Increased puddling of the surface soil was also responsible for the higher rate of run-off.

As for erosion, it is clear that cultivation involving little movement of the soil leads to a much smaller soil loss than that which occurs after intensive working. Mean annual erosion for the complete crop rotation was only 772 tons per sq. km. under peasant cultivation, but it rose to 1,623 tons per sq. km., more than twice as much, under mechanised cultivation. Nevertheless, the latter method has the advantage of higher crop yield, viz. in 1956, 1,840 kg. per hectare of groundnuts compared with 970 kg. per hectare under peasant cultivation. This shows that the plough remains the best instrument for working the soil but it must be used rationally. If man uses it in conjunction with soil conservation cultivating techniques, intensive cropping is no longer a danger but becomes a factor for progress.

B.—THE CAUSAL FACTOR OF SOIL EROSION BY WATER : ATMOSPHERIC PRECIPITATION

Everywhere in the world where hydric erosion occurs, atmospheric precipitation is the cause and predominating factor. To study the effect of rainfall one must also study the relations between its characteristics (total, intensity and frequency), and run-off and erosion. Although this has not been neglected in the French-speaking African countries, the most extensive research in Africa has been done by Hudson (Southern Rhodesia) to whom frequent reference must be made on this subject.

I. Effect of Total Rainfall

The African continent has an extremely wide range of rainfall and the question of the existence of relations between rainfall and erosion arises. All the experiments carried out have shown that very frequently there are no such relations, or at least that total rainfall, considered in isolation, does not account for liability to erosion by rain.

Hudson showed this on a annual basis (Table VII). There is no relation between the annual figures for rainfall, erosion and run-off, the latter being expressed both as a percentage and in terms of total run-off.

Table VII.—Rainfall, run-off and erosion recorded over five years under maize crops and Napier grass on slopes of 3%, 4·5% and 6%; average figures for six plots (Henderson Research Institute, Mazoe, Southern Rhodesia)

Rainy season	Rainfall mm.	Erosion t/hectare	Runoff	
			mm.	%
1953–54	917·2	5·12	91·18	9·94
1954–55	1,129·8	1·23	56·86	5·03
1955–56	907·8	3·44	49·53	5·46
1956–57	962·2	5·72	71·37	7·42
1957–58	696·5	3·36	51·56	7·41

As individual downpour total is one of the factors in soil saturation and hence in the origin of run-off, it could be assumed that though there is no relationship between total rainfall and erosion over long periods there is a relationship at individual downpour level. The experiment carried out at the ORSTOM Research Centre of Adiopodoumé (Ivory Coast) disproved this assumption (Table VIII).

For the same category of downpour, 32 to 36 mm., under six conditions of natural environment, soil loss and run-off are extremely variable.

Although the action of the vegetation might provide an explanation for plots p1, p2, p4 and p5 (better protection of the soil at the end of the rainy season), plots p3 and p6 show no correlation in environments which do not vary during the year. Another characteristic of rainfall must intervene.

Table VIII.—Soil loss and run-off recorded for the same category of rainfall in 1956 at Adiopodoumé, ORSTOM Centre (Ivory Coast)

Date	P mm.	p1		p2		p3		p4		p5		p6	
		E kg/ha	R %	E kg/ha	R %	E kg/ha	R %	E kg/ha	R %	E kg./ha	R %	E kg./ha	R %
12/6	33	789	36·5	1,188	31·7	910	35·8	898	26·9	168	20·9	14	2·2
23/6	32·1	2,197	44·9	3,751	47·9	4,189	41·2	1,782	41·2	800	35·1	33	1·6
3/7	31·6	418	31·4	1,022	42·8	927	38·1	552	31·7	200	26·4	19	3·8
5/7	33·1	411	8·4	458	7·9	437	7·9	169	6·8	137	5·6	6	1·7
23/10	35·9	1	0	118	9·9	332	9·3	31	0	2	0	2	0
6/12	32·8	3	0	182	29·5	3,694	40·3	29	0	73	0	22	0

p1 : sown with *Crotalaria usaramoensis*, flat, 7 May
p2 : transplanting of manioc on ridges, 7 May
p3 : plot kept bare by weeding.
p4 : sown with *Eleusinogia compesta*, flat, 7 May
p5 : pineapple crop planted on the contour, flat.
p6 : secondary forest.

II. Effect of the Intensity of Downpours

(1) Puddling Effect of Raindrops

Consideration of the mechanism of water erosion indicates that one of the main effects of atmospheric precipitation is the formation of fine particles likely to be washed away by run-off. Soil aggregates are generally too large to be easily removed by run-off, but raindrops, having kinetic energy, exert a mechanical action at their point of impact with these aggregates, which are already moist. They detach fine particles from the surface of the aggregates and form a suspension with them due to splash effect.

There are some remarkable photographs of this phenomenon, but it took almost twenty years before it was generally acknowledged that this is by far the greatest source of disaggregation of fine particles of soil, which are then carried away by run-off in the course of erosion.

Hudson clearly demonstrated (Henderson Research Institute, Mazoe) the result of the action of raindrops by comparing the reaction of three different adjacent environments to rain. Two experimental plots were kept bare by hand weeding, but gauze was suspended 10 cm above one of them. It was intended to absorb the kinetic energy of the raindrops without modifying the water exchange between the atmosphere and the soil. In particular, it allowed all the water supplied by the rain to reach the soil, but first absorbed its kinetic energy. The third environment was a dense grassland of *Digitaria swazilandensis*.

Table IX shows the results of the run-off and erosion measurements carried out during this experiment.

This table shows how the effect of splash can, under certain textural conditions, block up surface porosity and hence increase the amount of run-off. The presence of gauze to prevent splash effect led to an 8 to 40-fold reduction in run-off by maintaining the original state of permeability. Likewise, as fine particles were not detached under the gauze, erosion became minimal in relation to that recorded on bare ground.

At the Niangoloko IRHO Station (Upper Volta), a system for measuring

Table IX.—Study of raindrop impact, Henderson Research Institute, Southern Rhodesia, 1953–56

Year	P mm.	Measurements	Bare soil	Bare soil plus gauze	Dense grassland—*Digitaria*
1953–54 . .	917·2	E t/acre	61·5	0	2·9
1954–55 . .	1,129·[illegible]	R % E t/acre	48 225·8	6 0·9	8 0·3
1955–56 . .	907·8	R % E t/acre	41 60·1	1 2	2 0·1
Average 1953–56	984·9	E t/acre	115·8	0·96	1·1

the particles of soil detached by splash was set up to assess the extent of the phenomenon on sandy tropical ferruginous soil which is rather unstable (sand: 92%, silt: 5%, clay: 3%). Bottles stoppered by funnels 20 cm. in diameter were buried in the soil, with the upper level of the funnel rising a few millimetres above the soil to avoid disturbance due to run-off. Each bottle was placed at the centre of an area circumscribed by a cylinder 40 cm. high and mounted on small feet. The radius of the cylinders varied from 40 to 120 cm. Table X gives an example of the results obtained in 1956.

Table X.—Study of raindrop impact at Niangoloko (Upper Volta). Weight of soil collected in the bottles in grammes per 314 sq. cm., originating from different areas and for three categories of downpour

Radius of cylinder cm.	Rainfall of 46 mm.	Rainfall of 22 mm.	Rainfall of 9 mm.
120	39·7	25·6	7·4
80	33·4	11·4	6·2
60	17·8	6·2	1·8
40	5·5	1·5	1·7

Above 120 cm., the weight of earth remains approximately the same, which indicates that in the Sudan-Guinean climate solid particles can be transported up to 1·2 metres simply as a result of splash effect.

During 1957, 533 grammes of earth dislodged by splash fell on 314 sq. cm. (radius of cylinder: 120 cm). Theoretically that represents 17,000 tons per sq. km. Naturally that figure is only theoretical since the same particles can be subjected more than once to the effect of splash and there are numerous compensatory effects; but it does give an idea of the volume of fine particles liable to be washed away by run-off.

(2) Effect of rain intensity

Clearly, in view of soil detachability, the higher the kinetic energy of the raindrops, the greater the extent of detachment. The kinetic energy

of raindrops depends on their size and velocity, and the more intense the rain, the greater their size and velocity will be. Rainfall intensity should therefore be a more important factor in erosion than rainfall total.

This has already been confirmed in the United States and is also proved by the research carried out in Upper Volta, Madagascar and Southern Rhodesia.

A classical example relating to the United States is shown in Table XI.

It is most significant that soil erosion increases as rainfall becomes more intense.

Table XI.—Effect of the intensity of rain on soil erosion. Classification of 183 erosive downpours on the basis of their intensity (Zanesville, Ohio, 1934–42, bare ground)

Category of rain intensity (mm. per hour during the 5 minutes of greatest intensity)	Number of downpours	Average erosion per downpour (tons per sq. km)
0–25·4	40	375
25·4–50·8	61	595
50·8–76·2	40	1,178
76·2–101·6	19	1,144
101·6–127	13	3,424
127–152·4	4	3,632
152·4–177·8	5	3,872
228·6–254	1	4,793

Research was carried out at the Niangoloko IRHO Station (Upper Volta) in 1956–57 using a Ramon-Jardy rain-gauge recording instantaneous rain intensities. This research enabled downpours and erosive downpours to be classified in categories of rain intensity (Table XII).

Table XII.—Distribution of downpours and erosive downpours according to categories of maximum instantaneous rain intensity (Niangoloko IRHO Station, Upper Volta)

Categories of maximum instantaneous rain intensity (in mm./min.)	0 to 0·4	0·5 to 0·9	1 to 1·4	1·5 to 1·9	2 to 2·4	2·5 to 2·9	3 and over
1956							
No. of downpours	15	20	14	5	4	1	3
No. of erosive downpours	0	2	2	3	4	1	3
Percentage of erosive downpours	0%	10%	14%	60%	100%	100%	100%
1957							
No. of downpours	19	10	13	8	3	3	1
No. of erosive downpours	1	0	3	5	3	3	1
Percentage of erosive downpours	5·2%	0%	23%	62%	100%	100%	100%

Table XII shows that downpours with a maximum instantaneous intensity of less than 1·5 mm. per minute are very rarely erosive. A calculation of the percentage of the weight of soil washed away during the year represented by the weight of the soil washed away by those downpours alone shows that it was only 4·7% in 1956 and 2·5% in 1957. However, erosion occurs frequently when the maximum instantaneous rain intensity exceeds 1·5 mm. per minute, and always occurs when it reaches and exceeds 2 mm. per minute. The percentage of the total weight of soil eroded during the year under the latter conditions was 88% in 1956 and in 1957.

The value of 2 mm. per minute maximum instantaneous intensity is also the point at which erosion starts in Madagascar. As the use of intensity rain-gauges is not widespread, other research has been carried out there, as a result of which downpours of a maximum intensity of:

7 mm./15 minutes are considered as low intensity.

7–15 mm./15 minutes are considered as medium intensity.

15 mm./15 minutes are considered as high intensity.

And here, too, high intensity downpours are responsible for erosion (Table XIII).

Table XIII.—Percentage of annual erosion due to high intensity downpours at Nanisana (Madagascar)

Year	No. of erosive downpours	Percentage of annual rainfall	Percentage of annual erosion
1959–60	7	21	85
1960–61	10	30	80
1961–62	7	24	85
1962–63	16	45	85
1963–64	7	27	80

(3) Analysis of the erosiveness of downpours

Hudson, following in the footsteps of other researchers, made a more detailed analysis of the process of rain intensity and its effects.

All the authors concerned have pointed out that **the kinetic energy of falling raindrops is the cause of the erosiveness of downpours.**

A drop of water of mass m and velocity v has a kinetic energy expressed by $\frac{1}{2}mv^2$.

Raindrop is calculated from the diameter of a drop assimilated to a sphere. Maximum diameter is about 9 mm. Larger drops disintegrate automatically due to insufficient surface tension. In a turbulent atmosphere the maximum diameter generally does not exceed 5 to 6 mm.

The velocity of raindrops depends on their mass and hence on their diameter. It is not constant throughout the fall, but increases to a limiting or terminal velocity.

This is reached when the distance travelled exceeds 20 metres, which is the case with natural rain. Table XIV shows increase in terminal velocity with increase in raindrop diameter.

Table XIV.—Terminal velocities and heights of fall required to attain them. (Laws, 1941 ; Gunn and Kinzer, 1949)

Diameter of drops (mm.)	Terminal velocity (m./sec.)	Height of fall necessary to attain 95% of terminal velocity (m.)
0·25	1	—
0·50	2	—
1	4	2·2
2	6·5	5
3	8·1	7·2
4	8·8	7·8
5	9·1	7·6
6	9·3	7·2

The speed of fall of the drops increases less rapidly than their diameter, because of air resistance to penetration by large drops.

The wind also affects speed of fall and Hudson considers that the actual velocity Vr of a drop falling obliquely on to the ground at an angle α to the vertical is related to the corresponding vertical velocity Vv, other things being equal, by the equation

$$Vr = \frac{Vv}{\text{Cos } \alpha}$$

On the basis of the above, **the kinetic energy of a downpour can be calculated if the size of the drops, their quantity and their size distribution within the downpour are known.**

—Size distribution of raindrops varies according to individual storms and is related to rain intensity (see Fig. 1).

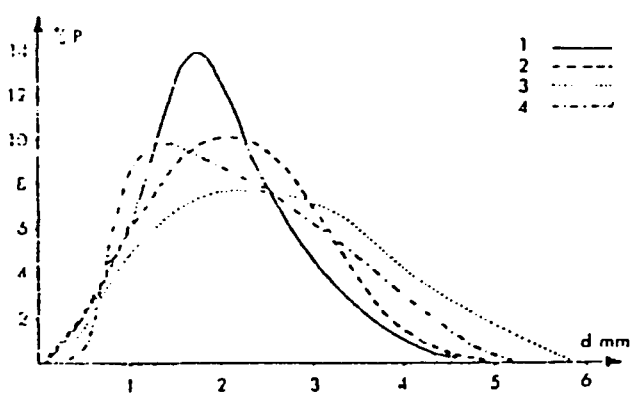

Fig. 1.—Raindrop size distribution (categories of 0·25 mm.) according to intensity of the downpour (after Laws, 1941, and Hudson, 1961).
% P : percentage of total rainfall ; d : diameter ; Intensities : 1 = 12·5 mm./h. ; 2 = 12·5 to 37·5 mm./h. ; 3 = 62·5–112·5 mm./h. ; 4 = more than 150 mm./h.

—For want of a better parameter, the size distribution of raindrops has been characterised by the " median diameter " (denoted by D_{50}). This is the diameter at which the total volume of drops of larger size equals the total volume of drops of smaller size. In this case, relations were immediately found between median diameters and rain intensities (see Fig. 2). It

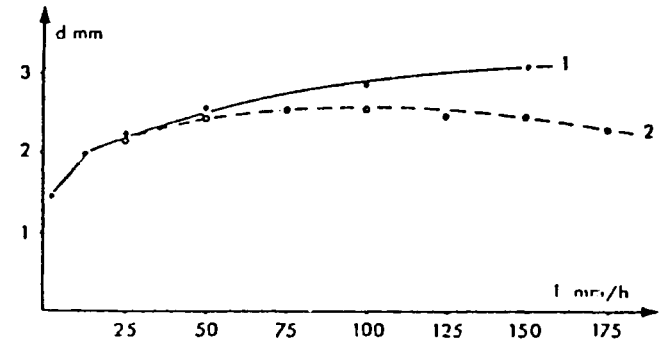

Fig. 2.—Variation of the median diameter of drops (d) with storm intensity I. (1) United States, after Elkern (1950) ; (2) Rhodesia, after Hudson (1963a).

should be noted that Hudson considers the median diameter to be stabilised at 100 mm./hour rainfall and even to decline slightly beyond that since the larger the drops of water the more frequently they burst as they fall.

—As terminal velocity depends on raindrop size, it is seen from the two points noted above that terminal velocity will also depend on storm intensity.

Consequently, all researchers eventually tried to **establish the general relation or relations between rainfall intensity and kinetic energy.** These relations may be numerous as downpours of different intensity but of similar total rainfall must be compared.

An example of the results obtained by Elkern in the United States is given in Table XV.

Table XV.—Kinetic energy supplied by downpours of similar total rainfall but of different intensities

Intensity mm./hour	2·5	12·5	25	50	100	150
Kinetic energy 10^3 ergs/sq. cm.	18·3	32·1	39·8	48·2	57·2	63

Smith and Wischmeier proposed the following general relation :

$$Ec = 916 + 331 \log I.$$

Ec being expressed in foot-tons per acre and per inch of rain and I being the intensity of rain in inches per hour.

Hudson refers to the relations defined by himself and two other researchers (Fig. 3).

That Figure shows that kinetic energy increases very rapidly as the intensity of rainfall rises, provided the latter remains below 100 mm./hour, and then tends towards a constant value. According to Hudson, the explanation for this is the bursting of raindrops at very high rainfall intensities.

The disagreement between researchers probably results from differences

in the relations established by them between rainfall intensity and raindrop size distribution within downpours, since there is agreement on the relation between size of drops and terminal velocity.

Finally, the following points show the full importance of rainfall intensity as a factor affecting erosion:

(*a*) It is related to the kinetic energy of the rainstorms, which determines their erosiveness.

(*b*) It is generally measured in meteorological stations whereas measurement of kinetic energy, direct or indirect, is very difficult.

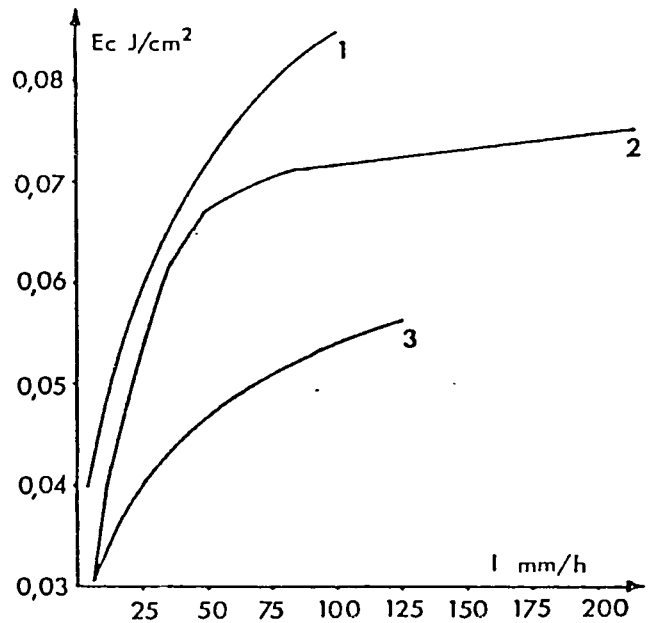

FIG. 3.—Intensity—kinetic energy relations (for 25 mm. of rainfall) depending on climates and authors (after Hudson, 1963b).
I: Intensity of the downpour; E: Kinetic energy in joules/sq. cm.
Curves: 1 = storms (Kelkai); 2 = Rhodesia (Hudson): 3 = Japan (Mihara).

However, when the effect of individual rainstorms on soil loss is analysed it is clear that any accurate analysis of the phenomenon must take into account a third characteristic of rainfall, viz. storm frequency.

III. Effect of Storm Frequency

In tropical and Mediterranean regions one characteristic of downpours is their repetition at frequent intervals throughout the rainy season, i.e. daily rain is a common occurrence.

One can easily imagine what phenomena then occur. The soil has no time to dry out between two downpours, saturation point is quickly reached and subsequent downpours, whatever their characteristics, run off the soil instead of percolating into it. Moreover, detachment of fine particles occurs when soil aggregates are covered with a film of water.

With a high storm frequency, some downpours, although of lesser total rainfall or intensity than others, may cause a higher level of run-off or erosion. Table XVI illustrates this possibility.

Table XVI.—The effects of two successive downpours at Lake Alaotra (Madagascar)

Date	Rainfall (mm.)	Duration of downpour (min.)	Erosion (t/ha)	Run-off %
23.12.1959. . .	26	30	1	5·4
24.12.1959. . .	24	90	3·3	39·4

Despite the fact that it was only one-third as intense as the first downpour, the second downpour caused a higher level of run-off and erosion than the first, as it fell on soil which the first downpour had made more susceptible to water erosion.

A final conclusion can be drawn from all the research carried out in Africa on the action of atmospheric precipitation: **the degradation suffered annually by the soil occurs in an extremely short period of time.** At Niangoloko (Upper Volta) 88% of the annual erosion occurred in 831 minutes in 1956 and in 370 minutes in 1957, i.e. in approximately 14 hours and 6 hours respectively. It is clear that the majority of annual soil loss occurs in only a few hours, and this is typical of Africa.

C.—CONCLUSION: INTEGRATED STUDY OF THE FACTORS AFFECTING SOIL EROSION BY WATER

When the many factors involved in processes occurring in a natural environment are studied and an attempt is made to assess the relationships between processes and environments, each factor must be considered separately and its action determined. This has so far been done in Africa, as regards soil erosion by water, on the basis of experimental plots.

But it is obvious that all these factors are interrelated and also act simultaneously. In the end an integrated study must be made of the process and the factors involved it it. This type of study is not yet very highly developed in French-speaking Africa (experiments in Tunisia and Senegal) but it can be attempted on the basis of Wischmeier's universal equation for soil loss.

The American Soil Conservation Department, with its many experimental plots already in operation for several decades, has succeeded in establishing this universal equation, the principle of which is applicable everywhere.

It takes the form:

$$A = R\,(K.L.S.C.P.)$$

A represents soil loss in tons per acre (American short tons equivalent to 907·184 kg.).

R, or rain index, indicates the aggressiveness of rain. It can be calculated for one rainstorm or for all rainstorms in a given period. A represents the soil loss for the same period as R. Generally an average annual rain index calculated from the rainstorms over several years is used. A then represents the average annual soil loss. R is the only factor in the second term of the equation which has a dimension, as all the others are ratios. Other things being equal, erosion is proportional to the rain index.

For a given rainfall, the number of units of R is equal to the kinetic energy of the rain (in foot-tons per acre) multiplied by the maximum intensity in 30 minutes expressed in inches per hour, divided by 100.

To calculate the kinetic energy of a rainstorm, one must have a recording of it on a rain-gauge. On that recording, the rainstorm is divided into sections of equal intensity. Each section is therefore characterised by a given number of inches falling at a given uniform intensity. Wischmeier has established a relation between the unit kinetic energy of a rainstorm of uniform intensity and that intensity. That relation is as follows:

$$Eu = 916 + 331 \log Ih$$

where Eu is the unit kinetic energy in foot-tons per acre per inch of rainfall, and Ih is the uniform intensity of the rainfall in inches per hour. The energy of the section is equal to the unit energy per inch of rainfall multiplied by the number of inches typical of the section. The total energy of a rainstorm is equal to the sum of the energies of each section.

K, or soil index, a factor without dimension, measures the relative resistance to erosion of a soil. Its values are obtained experimentally: it is the soil loss in short tons per acre per unit of R when all the other coefficients in the second term of the equation are equal to one.

L.S., or slope index, a factor without a dimension, enables the topographical conditions of a site to be compared with standard conditions. It indicates the effect of the gradient and length of the slope. It is the ratio of the soil loss of a field with a given gradient and length to that of a field of standard dimensions, all other environmental conditions being equal. A gradient of 9% and a length of 72·6 feet (22·12 m.) are the standard dimensions, or equal to one.

C, or crop index, a factor without a dimension, makes it possible to allow for the fact that rain has a proportionally greater action on bare soil than on covered soil. It characterises the crop, viz. the type and sequence of crops, degree of mineral fertilisation (level of productivity) or organic fertilisation (treatment of crop residues).

It is the ratio of the soil loss on land cultivated under specific conditions to that of continuously worked fallow land (C = 1), all other conditions being equal.

P, or water and soil conservation index, characterises the practices conserving a certain proportion of soil. It is the ratio of soil loss on a field in which conservation practices are applied to that of a field cultivated along the line of the steepest slope (P = 1), all other things being equal.

Applied to a given region, Wischmeier's universal equation provides an integrated study of the factors involved in soil erosion and not only enables soil loss to be estimated but also gives an idea of the anti-erosion measures to be taken to ensure that a soil loss threshold beyond which erosion becomes dangerous is not exceeded. The degree of effectiveness of such anti-erosion measures in Africa will now be considered.

* * *

PART II

RESEARCH ON SOIL CONSERVATION IN AFRICA AND MADAGASCAR

Man's main concern when he tills the soil should be to maintain its productive capacity while producing crops. This concern leads him to use rational agricultural methods. These generally consist of soil conservation methods, but in the struggle against erosion certain problems arise which can only be solved by applying special methods.

For the last thirty years, special attention has been devoted to all these methods of soil conservation all over the world. It was necessary to ascertain their efficiency in Africa, in tropical and Mediterranean climates, before making plans for the rational farming of the land, and this need led to the research whose results are described here.

There are two series of soil conservation means:

(*a*) "Mechanical" means which control run-off and hence erosion.

(*b*) Biological means giving the soil increased resistance to attack by water by the use of vegetation and cultivation practices.

A.—SOIL CONSERVATION BY CONTROLLING RUN-OFF

I. Terracing of the land

Terracing is one of the best-known methods of controlling run-off and erosion.

When the slope is slight, there are two possible methods:

(*a*) If rainfall is plentiful, the speed of run-off must be reduced and the water which does not infiltrate into the soil must be drained off at a non-erosive speed. Without modifying the slope, the land is laid out in a series of crop strips, the longtitudinal direction of which forms an open angle with the contour lines. The downhill side of each strip is limited by a combination of an embankment and trench. This arrangement forms diversion terraces.

(*b*) If rainfall is mediocre, run-off speed must be reduced and stock the

water in the soil. In this case each strip runs directly parallel to the contour and functions as a closed basin. The slope is left unmodified. This arrangement forms retention terraces.

When the slope is steep cultivation presents a problem. In that case, level and bench terraces, modifying the slope, solve the problem.

The difference in level between two successive channels, two steps or benches is the fundamental factor in designing a terrace system. It determines the width of each element of the terrace system. There are numerous formulae relating the difference in level to the gradient of the existing slope.

Diversion terraces and bench or level terraces are the maintypes which have been studied in Africa to determine their conservation efficiency.

(1) Diversion Terraces

Ramser's formula: $D = 0{\cdot}076\ P + 0{\cdot}608$, where D is the difference in level between two successive channels in metres and P is the percentage of slope, has been used to design diversion systems.

Some of the results obtained when no method of soil conservation other than terracing was used are given below (P = annual rainfall in mm., R = annual run-off as % of P, E = annual erosion in tons per sq. km.).

	P	R	E
Sefa Station (Senegal). Slope 2%			
1954 Mechanised groundnut cultivation	1,303	47	1,728
1955 Mechanised rice cultivation	1,395	49·3	2,713
1956 Mechanised groundnut cultivation	1,265	39·5	1,075
Kindia Station (Guinea). Slope 6%			
1956 Citrus cultivation on bare soil	1,342	9·4	1,787
ORSTOM Centre at Adiopodoumé. Slope 7%			
1956 Bare soil	1,939	23·6	11,770
1956 Manioc cultivation on ridges	1,939	20·8	9,277
1957 Bare soil	2,383		10,447
Niangoloko IRHO Station (Upper Volta). Slope 2·5%			
1956 Groundnut cultivation, flat	516	10·4	541
1957 Millet cultivation, flat	1,400		748

(2) Bench Terraces

	P	R	E
Seredou Station (Guinea). Slope 25% (June 1955–June 1956)			
Control plot: cinchona, flat on contour lines 1 metre apart, at 1 metre intervals in the rows	2,934	6·5	2,448
Plots on horizontal benches 1 metre wide with one row of cinchona on each bench	2,934	6·45	721

(3) Study of Results and Conclusions

Bench terraces proved efficient in reducing erosion on steep slopes but have no effect on the amount of run-off. This is because of the change

undergone by the soil when the benches are being constructed. The humus-bearing upper horizon which has a high water retention capacity is disrupted and possibly even buried. The powerful mechanical tamping necessary to make solid benches reduces permeability. The effect obtained therefore is chiefly a reduction in the speed of run-off and retention of the soil.

If the soil losses measured on diversion terraces in Africa are compared with those considered catastrophic in the United States under similar experimental conditions, the former are seen to be higher in all cases:

Watkinsville (Georgia)	Mechanised groundnuts, slope 3%	1,321 t/sq. km./annum
Spur (Texas)	Mechanised groundnuts, slope 2%	1,584 t/sq. km./annum
Sefa (Senegal)	Mechanised groundnuts, slope 2%	1,728 t/sq. km./annum
Guthrie (Oklahoma)	Continuous cotton, slope 7%	3,779 t/sq. km./annum
Tyler (Texas)	Continuous cotton, slope 8·75%	5,045 t/sq. km./annum
Statesville (Carolina N.)	Continuous cotton, slope 10%	7,053 t/sq. km./annum
Adiopodoumé	Manioc, slope 7%	9,277 t/sq. km./annum

Only one conclusion can be drawn: diversion terraces, suitable for slopes of less than 10–12%, are on their own inadequate to combat erosion in Africa. Used without any other anti-erosion method of cultivation or when the soil is bare, they almost always allow dangerous (1,728, 2,713 tons/sq. km./annum) if not catastrophic soil losses (9,277, 11,770 tons/sq. km./ annum). Additional anti-erosion methods of cultivation must also be applied.

II. Tillage

When the slope is slight, working the soil is one of the most effective measures to control run-off and reduce erosion.

(1) Contour Ploughing

(1.1) Effects of contour ploughing. When land is ploughed along the contour one obtains a series of furrows always at right angles to the line of the greatest slope and very close to each other. These furrows retain water. This method of preparing the soil makes it possible to break up the run-off and considerably reduce the speed of water flow.

There are few figures available in Africa or Madagascar to illustrate the efficiency of this method, but Table XVII gives some indication of it on the basis of an example from the United States.

This experiment, carried out at the Bethany (Missouri) Station clearly shows the effect of contour ploughing and also demonstrates that its effect is much more decisive than that of terracing since the latter method only caused a slight additional reduction in erosion in comparison to the high reduction brought about by contour ploughing alone. The minor effect on run-off is probably due to the fact that the average slope is already somewhat steep, i.e. 6 to 7%.

(1.2) Limits to the use of this method of soil conservation. The last finding indicates that there are limits to the use of contour ploughing

Table XVII.—Annual precipitation (P), run-off (R) and erosion (E) in three comparable cultivated experimental basins

(1) Without soil conservation.
(2) With contour ploughing and drainage channels.
(3) With contour ploughing on diversion terraces.

Year	P (inches)	Crop	R (%)			E (tons/acre)		
			1	2	3	1	2	3
1934	21·26	Oats	19·8	27·9	25·3	40·01	24·04	
1935	36·07	Wheat	32	28·6	22·1	47·38	16·96	
1936	24·77	Grassland	8·2	7·8	5·6	0·88	0·11	
1937	21·63	Maize	16·1	18·8	13·8	19·71	1·82	
1938	26·13	Oats	4·7	2·7	2·7	2·62	0·16	0·05
1939	26·68	Wheat	20	13·7	13·2	25·84	0·77	0·63
1940	27·62	Grassland	7·7	7	6	3·27	0·07	0·04
1941	35·04	Maize	16·3	16·3	13·4	63·93	1·37	1·12
1942	32·89	Oats	17·7	17·7	10	38·44	0·78	0·58

as a method of soil conservation. The gradient of the slope is a limiting factor. Fig. 4 clearly shows that the volume of water retained by a furrow system declines as the gradient of the slope increases.

Moreover, even if the level of run-off water remains low because it soaks in better when the soil is tilled, the speed of flow increases as the gradient of the slope increases, so that it is better able to wash away soil and hence soil losses increase. In other words, the lower the gradient of the

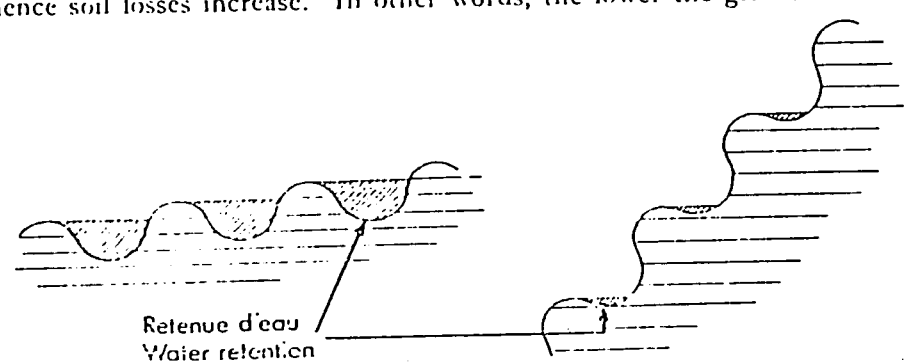

FIG. 4.

slope the more effective is contour ploughing. Experiments carried out in Madagascar at Lake Alaotra show that on a slope of 8% the method is considerably less advantageous although it still has some effect. Measurements effected at Sefa (Senegal), Pretoria (South Africa) and Mazoe (Southern Rhodesia) all indicate that a slope of 3 to 3·5% is the limit beyond which the effect of contour ploughing generally starts to decline.

This method of combating run-off and erosion can only be used on land which is sufficiently permeable both on the surface and at depth. Indeed, the growth of some plants may be hindered by an excess of water which can neither soak into the ground nor drain away. Also, if there is an impermeable horizon it may cause saturation of the horizon lying above it,

resulting in loss of cohesion and catastrophic soil loss. More simply, the soil may give way between the furrows under the effect of a heavy load of water and rills may be formed, bringing with them a danger of serious erosion. A similar phenomenon occurs when water collects at certain points on badly ploughed land, viz. poor junctions between furrows.

However, allowing for the limitations to its utilisation, contour ploughing is, with cultivation on ridges, one of the best methods of preventing run-off and erosion on gentle slopes.

(2) Contour Ridging

Cultivation on ridges, known to and practised by the African farmer, is a similar technique to contour ploughing when the ridges are situated along the contour, or form a narrow angle with it. Tie ridging on the contour promotes total absorption. If the climate is very aggressive and there is a danger of overflow (the steeper the slope, the more catastrophic this would be), the technique of ridging with a slight longitudinal slope can be applied. Whatever the type used, ridging retains more water than contour ploughing because of the height of the ridges.

Table XVIII.—Adiopodoumé (Ivory Coast): Effect of pineapple growing on contour ridges. Slope 7%

Method of cultivation	Time of year	P (mm)	Erosion tons/sq. km.
Pineapple grown flat, after clearing	5/1956–3/1958	4,575	14,077
Pineapple grown flat as second crop	3/1958–5/1959	1,547	7,894
Pineapple on ridges, after clearing	3/1957–3/1959	2,402	1,622

The difference in behaviour of the two environments to the erosiveness of the rainstorms is obvious.

Table XIX.—Bouaké (Ivory Coast): Effect of tie ridging compared with traditional cultivation (1960). Slope 4%

Method of cultivation	R (%)	R max. (%)	Erosion t/hectare
Traditional cultivation of yams	30·7	53	4·31
Maize plus cotton on tied ridges	3·6	30	0·84

The effect of tie ridging on run-off is obvious: the water is stored in the soil and erosion is reduced five-fold.

Table XX.—Sefa (Senegal): Effect of tie ridging compared with flat cultivation. Slope 1%

Method of cultivation	R (%)	Erosion (t/sq. km.)
Rice flat	22·3	621
Groundnuts flat	9·1	305
Cotton on tie ridging	0·6	47

(2.1) Effects of contour ridging. The efficiency of this method has been demonstrated in many places in Africa. Ridging has proved fully effective, but it is surprising that the less steep the slope the greater effect it has. Erosion is reduced seven-fold at Adiopodoumé (slope 7%), five-fold at Bouaké (slope 4%) and thirteen-fold at Sefa (slope 1%). Run-off is reduced eight-fold at Bouaké (slope 4%) but is thirty-seven times less at Sefa (slope 1%).

Table XXI.—Nanokely (Madagascar): Effect of contour ridging on erosion compared with flat cultivation (average 1958-63). Slope 8%

Crop	Flat	On ridges
Maize	19·1 t/hectare	3·9 t/hectare
Potatoes	5·1 t/hectare	4·2 t/hectare
Groundnuts	12·3 t/hectare	4·1 t/hectare

The same effect is therefore found in Madagascar and a survey of the results obtained indicates that to be effective ridges in Madagascar should be 25 cm. high at a spacing of from 80 cm. to 1 metre.

(2.2) Effects of slightly sloping ridges

Table XXII.—Niangoloko (Upper Volta): Comparison of the effect of tied contour ridges, open ridges with a 0·5% slope and flat cultivation on run-off, erosion and yields (average 1956–1960 for two crops). Slope 2·5%

	R (%)	E (t/sq. km.)	Yield kg./hectare	
			Groundnuts	Millet
Closed contour ridges	0·91	143·7	845·7	729
Open sloping ridges (0·5%)	6·27	610·4	479	376
Flat cultivation	12·15	1,318·6	658	352

This result again indicates the great advantage of using tied contour ridges, but also gives an idea of the value of open sloping ridges, which reduce run-off and erosion by half in comparison with flat cultivation. It is quite possible that on less permeable soil, on steeper slopes or under more intensive rainfall the danger of breaking of contour ridges would make open sloping ridges more advantageous.

A detailed study of results at Niangoloko in 1956 and 1957 is significant (Fig. 5). The curves show that in 1956 the three rainstorms on 16 and 22 June and 27 September, which caused the greatest degree of erosion on flat groundnuts (1), were rendered innocuous by horizontal ridging (3). The effect of ridging was even more obvious in 1957. Millet grown on contour ridges suffered no damage. Sloping ridges prevented erosion on 14 September and reduced it on 5 and 17 July, on which dates the field cultivated flat suffered considerable soil losses.

Hudson and United States researchers (Copley in particular) have studied the problem of open sloping ridges in view of the advantages they

offer on impermeable soil or steep slopes. They studied the relations between the longitudinal slope of the ridges (0·5 to 2·5%), the level of run-off water, run-off speed and soil loss. Their research shows that at gradients steeper than 1% (Copley) to 2% (Hudson) there is no relation between amount of run-off and ridge slope. However, there is always a relation between the latter and run-off velocity, and hence the ability of run-off to

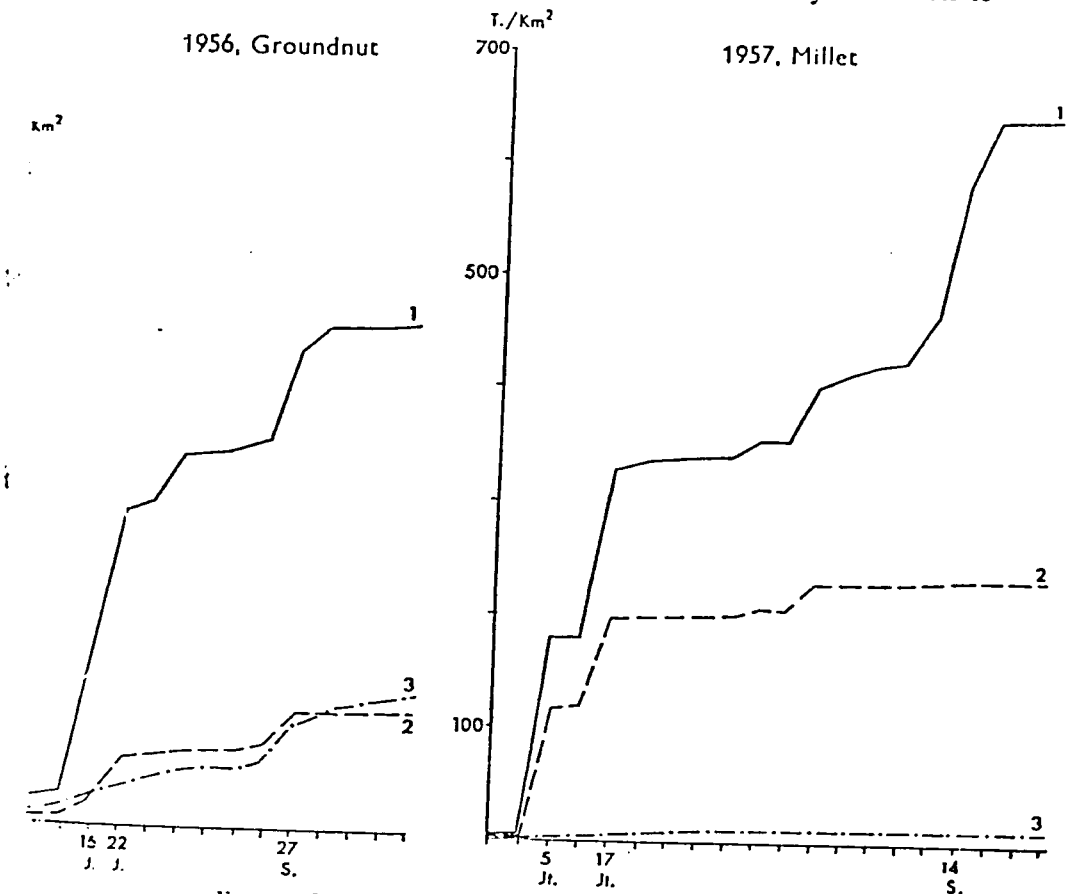

FIG. 5.—Cumulative curves of daily soil losses recorded:
(1) With flat cultivation.
(2) With open ridges sloping at 0·5%.
(3) With closed horizontal ridges.

wash away soil. That is the heart of the problem and ideal land management would consist of giving the ridges a slope sufficient to drain off excess water, but at a speed which is never erosive. Hudson considers that that slope should never exceed 1·5 to 2%.

(2.3) Analysis of the action of ridging. Granulometric analysis of eroded soil provides additional information on the action of ridges as regards the washing away of fine particles of soil. Table XXIII shows that the percentage of clay and silt is higher in erosion products from a ridged

field than in those from a field left flat. This is the result of the action of the ridges. As they brake the flow speed of the water the larger particles are more difficult to wash away than are the smaller ones which easily remain in suspension. Thus as many, if not more, fine particles as coarse particles reach the bottom of a ridged field. On a flat field sand is not retained and when the soil is very sandy, as at Niangoloko (90% sand) it predominates in the erosion products. That does not mean that fewer clay and silt particles are washed away. If the quantities of clay and silt lost by the Niangoloko experimental plots are assessed (see Table XXIII), it is clear that the fields cultivated flat lost twice as high a tonnage of such particles as those with open ridges on a 0·5% slope.

In conclusion, ridging, where permeability is sufficient, is extremely useful to control run-off and conserve the soil.

Table XXIII.—Granulometric analysis of the eroded soil on fields cultivated flat and on fields with open ridges with a 0·5% slope. Assessment of the quantities of sand, silt and clay washed away (Niangoloko IRHO Station—1956)

	Granulometric analysis			Quantitative assessment (tons per sq. km.)		
	Sand (%)	Silt (%)	Clay plus humus (%)	Sand	Silt	Clay plus humus
Flat cultivation	76·4	10·9	10·9	345·2	49·4	49·4
Flat cultivation	77·2	9	12·5	418·1	48·8	67·5
Open ridges, slope 0·5%	47·7	25·8	25·1	50·3	27·3	26·5

III. Trenches

Ridging is an effective cultivation technique to control run-off and reduce erosion. However, although it is easy to use on gentle slopes, it is more difficult to apply on steep slopes. In the latter case an anti-erosion device which is the opposite of ridging can be used, i.e. trenches are used instead of ridges. The Sérédou Station (Guinea) has tested the efficiency of this method of combating erosion on steep slopes.

Tied contour trenches were dug at Sérédou on a slope of 25%. Their dimensions were 2 m. × 0·3 m. × 0·3 m. and the ties were 0·2 m. thick. The trenches were 2·5 m. apart. Between them two rows of cinchona were grown, the rows being 1 metre apart and the distance between cinchona trees being 80 cm. The system was able to store the complete run-off from a 60 mm. downpour. The results were as follows:

Table XXIV.—Comparison of run-off and erosion under three conditions for the growing of cinchona on a slope of 25%. Sérédou (Guinea), 1956

Cultivation method	i' (mm.)	R (%)	E (t./sq. km./annum)
Cinchona flat	2,934	6·5	2,448
Cinchona on bench terraces (1 m. wide)	2,934	6·45	721
Cinchona on tied contour trenches	2,934	4·3	891

A comparison of the run-off and erosion recorded is to the advantage of the trenches. They achieve maximum water retention because the lowest run-off occurs. This is a clear advantage over bench terraces. Trenches are also as efficient as bench terraces in reducing soil loss.

Trenches have definite advantages over bench terraces on steep slopes, viz. they are easier to construct, they do not require large-scale machinery, they are less expensive and they save more water.

IV. Conclusion

Research already carried out in Africa on soil conservation by mechanical means indicates that diversion terraces are one method of controlling run-off and erosion but cannot by themselves protect the soil. A method of cultural conservation must be applied simultaneously and may be mechanical or biological.

Tillage operations (ploughing, ridging, trenching) are necessary to supplement the action of terraces, but their conservation effect within the limits mentioned (soil permeability is of vital importance in the design of anti-erosion works) is such that it may make terracing unnecessary or permit the construction of a looser and thus less costly system of terraces or a security system to control exceptional natural phenomena.

B.—THE USE OF BIOLOGICAL MEANS TO CONSERVE THE SOIL BY CONTROLLING RUN-OFF

Vegetation is obviously a vital factor in soil conservation. Its action may be seen everywhere. It is the foundation of biological methods to control run-off and erosion. When used in certain ways, its action is similar to that of mechanical means.

I. Strip-cropping

Strip-cropping consists of growing crops in a series of strips across the slope in such a way that when one strip is bare the two strips on either side of it are covered with vegetation, or when one strip has a crop which allows erosion, the two adjacent strips have erosion resistant vegetation.

This technique makes it possible to divide long slopes into a series of successive planes, some of which are designed to intercept run-off water, to reduce its speed of flow and consequently its capacity to wash away soil particles.

It has been tried out at Sefa Station (Senegal). (Table XXV).

Contrary to what might have been expected, judging from results obtained in the United States, strip-cropping did not prove particularly successful in soil conservation in the Sahelo-Sudanese climate. The reasons for this are perhaps the more erosive nature of the rain and the alternation of plants retaining soil but not water (rice).

Three times out of five, the run-off figures at Sefa for alternating strips

Table XXV.—Run-off, soil losses and yields for alternating crops and for individual crops of the plants grown in the alternating strips (Sefa, Senegal)

Year	Crop and method (alt. = alternating strips)	P (mm.)	R (mm.)	R (%)	E t/ha	Yields	
						Groundnuts	Rice
1955	Rice plus groundnuts (alt.)	1,340	295·9	22·1	11·44	1,780	1,760
	Groundnuts	1,340	24[illegible]·9	18	16·30	1,780	
	Rice	1,340	313·5	23·4	6·31		2,140
1956	Groundnuts—sorghum green manure (alt.)	1,148	132·8	11·6	[illegible]·57	1,636	
	Groundnuts	1,148	108·2	9·4	3·05	2,124	
	Rice	1,148	256	22·3	6·25		
1957	Sorghum green manure plus groundnuts (alt.)	1,004	135	13·4	6·70	1,920	
	Groundnuts	1,004	123·9	1[illegible]·3	6·72	2,020	
	Sorghum green manure	1,004	161	16	2·63		
1959	Groundnuts—rice (alt.)	742	124·8	16·8	2·47		
	Groundnuts	742	127·7	17·2	4·07		
	Rice	742	134·5	18·1	2·17		
1961	Rice—groundnuts (alt.)	1,185	374·3	31·6	7·05	1,940	534
	Rice	1,185	438·9	37	8·82		1,184
	Groundnuts	1,185	470	39·7	5·24	1,720	

were within the range of the figures measured for the individual crops. Soil losses seem to depend on the position of the plants in the alternating strips in relation to the measuring point. If rice or sorghum are at the top of the field, the losses measured below the groundnut strip are frequently close to those obtained for groundnuts alone (1955, 1957). If the strips are the other way round, the opposite may occur (1959). This indicates that anti-erosion strips do not have a decisive effect.

Finally, crop yields are often lower when strip-cropping is used, probably because of the more marked border effects.

Nevertheless, strip-cropping should not be ruled out, but it does need to be further developed.

II. Hedges and Buffer Strips

The results obtained in Africa with strip-cropping have led agriculturalists to try another spatial arrangement of vegetation to control run-off and erosion. The principle of alternating strips is adhered to, but the protective strips are reduced to a minimum size and introduced at more frequent intervals. This gives a system of hedges or buffer strips following the contour, which has two advantages in Africa. It means that a smaller area is taken up by erosion-resistant measures and yet multiplies them in space. These anti-erosion measures provide run-off control and, more particularly, ensure the retention of soil.

At Lake Alaotra in Madagascar, the action of contour hedges of

Pennisetum purpureum on run-off has been measured. The conclusion reached is that they cause from 750 to 1,150 cu. m. of water per hectare, depending on the region, to soak into the soil annually, which is equivalent to a rainfall of 75 to 115 mm.

Roose, at the ORSTOM Centre at Adiopodoumé (Ivory Coast) has studied buffer strips and in particular the effect of their width and plant composition. His most significant results, obtained on experimental plots with a slope of 7% with a manioc crop on ridges, are given in Tables XXVI and XXVII.

All these results show that the repetition of anti-erosion measures, consisting of hedges or buffer strips at frequent intervals, makes it possible to:

(*a*) Slow down run-off water. Grass is particularly advantageous in this respect because of its dense root system and foliage. It has the further advantages of multiplying quickly from cuttings or splitting of rootstocks as well as by seeding, and of having high resistance to compaction.

Table XXVI.—Effect of the presence of legumes in buffer strip vegetation (Adiopodoumé, 1965)

Vegetation of control strips	Annual R (%)	Max. R (%)	E (kg./hectare)
Manioc on ridges in alternate rows, *without control strips*, average of two plots	16·54	62·45	18,939
Manioc on ridges in alternate rows, control strips of *Digitaria*, etc., average of two plots	11·98	51·38	7,371
Manioc on ridges in alternate rows, with buffer strips of *Flemingia* or *Pueraria mixed with grasses*, average of two plots	7·26	29·95	1,381

Table XXVII.—Effect of buffer strips and their width on run-off and erosion at Adiopodoumé (1965)

Comparative environments	Annual R (%)	Max. R (%)	E kg. hectare
Manioc on ridges in alternate rows, *without control strips*, average of two plots	16·54	62·45	18,939
Manioc on ridges in alternate rows with buffer strips of *Digitaria*, etc., *2 metres wide*	14·98		12,088
Manioc on ridges in alternate rows, with control strips of *Digitaria*, etc., *4 metres wide*	8·98		2,653

(*b*) Increase infiltration. The study of individual rainstorms at Adiopodoumé in 1965 showed the reasons for the annual results given in Table XXVI. Although grass strips can soak up run-off water from low or average level rainstorms, they do not absorb all the water from high level rainstorms. On the other hand the introduction of taprooted legumes

improved the absorption capacity of the strips, which explains the advantage of legume-grass mixtures.

(c) Reduce soil loss. This reduction results from successive " braking " of run-off. Its capacity to wash away soil is reduced each time and when it reaches a hedge or control strip the solid particles suspended in it are deposited. Of course, the coarser particles are deposited more easily, which accounts for the fact that the proportion of fine particles in the solid mass washed away is higher on the far side of erosion control strip. Nevertheless, in absolute values a positive result is obtained for all types of particles. There is an optimum width for erosion-control strips at which highest efficiency is reached.

The action exerted by hedges and buffer strips eventually changes the slope as they lead to the formation of a series of small terraces as a result of sedimentation at the top of each buffer strip. Thus deep-rooting plants, which are well anchored and react well to soil compaction and accumulation, must be used in establishing such an erosion-control system. The system described is of great benefit in the conditions of African agriculture.

C.—SOIL CONSERVATION BY BIOLOGICAL MEANS

Vegetation is obviously a vital factor in soil conservation. The part it plays has been clearly shown in the preceding pages. Since man exploits the soil to produce plants, he disposes of biological means to combat erosion. He can in fact produce plants in such a way that they effectively protect the soil against water erosion. He can also use plants to improve soil properties and increase its resistance to erosion.

We shall not here consider the part played by large natural plant formations in the phenomenon of soil erosion, but shall deal mainly with the problems of rational agriculture.

I. Crop Management and Soil Conservation

(1) Effects of Crop Fertilisation

Plant morphology, the development of plant tops and roots and the method of planting determine the action vegetation can have in the struggle between water and soil. A given plant morphology, plant development and system of planting determine the level of action of the vegetation. But man can raise that level by acting on plant characteristics. Thus it is that fertilisation becomes a soil conservation factor in addition to being a factor affecting yield and the maintenance of soil fertility.

The problem of fertilisation in tropical and Mediterranean regions is still a subject of discussion between those advocating the use of " homeopathic " quantities at suitable times and those in favour of massive fertiliser applications to regenerate the soil before increasing crop yields. However,

one fact has emerged from the work of the few researchers who have tackled the problem from the point of view of combating soil erosion. It is shown in Tables XXVIII and XXIX.

Table XXVIII shows that a cover of maize reduces erosion considerably below that recorded on bare soil. But an additional advantage is provided by fertilisation, which gives a better development of foliage. The combination of a mineral fertiliser and an organic manure gives additional benefit as the improved development of foliage is accompanied by an improvement in the physical properties of the soil, in particular its structure (action of manure), and increased rate of infiltration.

Table XXVIII.—Comparison of the effects of different dressings applied to maize on a slope of 5% at Glen (South Africa), 1936–57

Dressing	Average annual run-off (%)	Average annual erosion (t/acre)
Bare soil, not worked	31·9	11·45
Non-fertilised maize	10·3	3·57
Maize plus N.P.K.	8·5	3·13
Maize plus P plus manure	7·6	2·93
Maize plus P plus cultivations between rows	6·2	2·08
Maize plus P plus mulching	6·6	2·94

Table XXIX.—Comparison of the effects of different treatments on bare soil and maize on a slope of 7% at Pretoria, South Africa, 1936–57

Treatment	Average annual run-off (%)	Average annual erosion (t/acre)
Bare soil, tilled ready for a maize crop	24·4	38·4
Idem plus kraal	20·9	33·1
Maize plus N.P.K.	23·6	29·2
Maize plus P plus kraal	22·9	25·9

The combination of mulching or tilling with a mineral fertiliser had the best effect in this experiment, but it was not very much better than the effect of organic plus mineral fertiliser alone.

Table XXIX confirms the results in Table XXVIII. The effect of an organic manure applied to bare tilled soil is evident, as is the effect of plant cover. But once again it was the combination of a mineral fertiliser and an organic manure on maize which gave the best result.

Consequently fertilisation provides man with an instrument to combat soil erosion, the most efficient method being the combination of mineral and organic fertilisation. This is only natural considering that the development of plants is closely related to their mineral nutrition, that mineral fertiliser needs an organic support and that the latter affects soil properties. Good fertiliser treatment has the effect of protecting a higher proportion of land by giving a crop with a denser cover and of improving soil cohesion as a result of better developed root systems.

(2) Effects of Crop Density

Fertilisation provides one method of covering a higher proportion of cultivated land and consequently leaving a smaller proportion exposed to the action of raindrops. Higher crop density is another method.

At Sefa (Senegal) on a slope of 2% and Seredou (Guinea) on a slope of 25% rice planted very densely (100 kg./hectare at Sefa) becomes an erosion-resistant crop because of its density. Erosion under mountain rice at Seredou was only 4·33 t/hectare per annum whereas with a rainfall of 2,733 mm. erosion on bare ground was 24·32 t/hectare.

Hudson, in Mazoe (Southern Rhodesia), using adequate fertiliser increased the density of a maize plot from 10,000 to 15,000 plants per acre. By means of photographs he estimated that the percentage of land exposed to rain action was reduced from 40% to only 10%. Table XXX shows the results of erosion and run-off measurements effected in both crop environments.

Table XXX.—Soil and water losses recorded on well-drained sandy soil at Mazoe (Southern Rhodesia) under two maize crops :
(1) High level of production (15,000 plants per acre, heavy fertilising).
(2) Low level of production (10,000 plants per acre, moderate fertilising)

	1955–56		1956–57		1957–58	
	R %	E t/acre	R %	E t/acre	R %	E t/acre
1	8	2·5	18	10·5	1	0·6
2	14	7·2	20	23·4	4	1·8

Allowing for the two levels of fertilisation, the result is significant, showing that erosion and run-off decline as plant density increases.

(3) Effects of Date of Sowing and Harvesting

The first two aspects of soil conservation by biological means show that the conservation value of a crop depends on the proportion of land that it protects from the action of raindrops. It is obvious, then, that the rapidity with which a crop covers the ground and the date at which it is harvested leaving the soil unprotected are factors which affect erosion and run-off.

In tropical regions with a dry season, the date at which crops are sown and harvested is particularly important because the most erosive rainstorms often occur at the beginning and end of the rainy season. At the end of the dry season the condition of the soil is such that it cannot be tilled until the first rains have fallen. Also, the excess of water at the end of the rainy season might damage the quality of the crop, which must therefore be harvested at the appropriate time. Tobacco provides a good illustration of the problem involved.

The vegetative period of tobacco in Southern Rhodesia is shorter than the rainy season. The grower is therefore faced with an alternative, viz. late planting which will protect the soil at the end of the rainy season, but leave

it bare at the start, or early planting which provides soil protection only at the beginning of the wet season.

Research carried out on experimental plots in Mazoe (contour cultivation, on sand, excellent crop cover), showed that the mean annual soil loss was three times higher with later planting than with early planting (4·5 and 1·6 tons per acre), while average run-off remained the same (15% of a total of 36·83 inches). The quality of the crop was also better with early planting. This result has governed the principles of tobacco growing when soil conservation is necessary.

(4) Effects of Companion and Catch Crops

When a crop provides poor soil cover, whether temporarily when it starts to grow or permanently because it has to be planted at wide spacings, the use of companion or catch crops to cover and protect as much of the ground as possible for as long as possible is another biological method of soil conservation.

The African peasant uses this practice and, for example, staggers the harvests of different companion crops ranging from manioc to fruit trees over a three-year period.

An experiment with plots carried out at the Nanisana Station (near Tananarive, Madagascar) shows the advantage of such practices in tropical agriculture (Table XXXI).

Table XXXI.—Run-off and soil losses recorded under different crops at the Nanisana Station, Tananarive, on brownish-yellow ferrallitic soil, 1958–59 (Rainfall 1,682·3 mm.)

Crop	R (%)	E t/hectare
Potatoes (flat)	12·8	15·3
Groundnuts (flat)	7·7	14·1
Maize plus mascatte peas (flat)	5·5	5·5
Chloris pasture (flat)	6·9	2·37
Melinis pasture (flat)	8·3	1·37
Potatoes (ridges)	14·3	14·1
Groundnuts (ridges)	11	5·62
Maize plus mascatte peas	6·2	2·62

Those results indicate the protection provided by pasture, but the companion crops of maize plus mascatte peas, very effective in preventing erosion even when grown flat, are as effective when grown on ridges as *Chloris* pasture grown flat. Here too the proportion of land protected and the length of time it is covered play a part.

(5) Effects of Mulching

Only the protective effects of growing crops have been studied so far. But after harvesting the land is theoretically bare until the next crop grows and is thus exposed to danger, especially if the ground is hilly and the soil susceptible to attack by water. In such cases crop residues can be used to provide soil cover. This practice is called mulching.

It affects the physical properties of the soil as it protects it completely from the action of raindrops. Consequently the soil is not affected by the beating of rain, surface porosity remains unchanged and soil hydrodynamic properties are maintained. Variations of temperature and humidity are also reduced under the mulch. Finally, run-off is considerably slowed down.

During decomposition plant residues enrich the soil chemically by providing organic substances and potassium. On the other hand, they promote the process of vertical leaching.

Finally, mulching intensifies biological activity (more uniform temperature and humidity), thus causing fixation of nitrogen, which can be used in an organic form, and probably of phosphorus.

From the strict point of view of prevention of run-off and erosion, mulching is one of the most efficient methods. In 1960 the mulching of a banana plot at the ORSTOM Station at Adiopodoumé caused soil loss to drop to the lowest level measured for the year viz. 5·18 kg./hectare, which was even lower than that measured on forested land, viz. 12·81 kg./hectare.

During the same period soil loss from the other crops tested was from 122·51 to 1,113·18 kg./ha.

Unfortunately there are limits to the widespread use of this soil conservation method in Africa. One is that 2,000 cu. m. of straw is required to provide a cover 20 cm. thick over 1 hectare. It is difficult to expect the African peasant to produce and transport such volumes. In addition, a costly level of fertilisation, particularly nitrate fertilisation, must be provided as well as mulching.

Fortunately mulching is not the only way of using crop residues. Hudson in Southern Rhodesia has studied the effect of incorporation of residues. This provides the soil with organic substances and bases with all the resultant advantages (improvement of physical and chemical properties of the soil, effect on crop growth). Hudson considers that under the experimental conditions he established the reduction in run-off and erosion brought about by ploughing in crop residues is three times higher than that obtained by increasing planting density (from 10,000 to 15,000 maize plants per acre).

II. The Problem of Crop Rotation : Cover Plants, Green Manures, Rotation

When the African farmer practises shifting cultivation, he is carrying out a crop rotation and the regeneration course is fallow of varying length. With the development of modern Africa, it is becoming increasingly necessary to modify that traditional form of agriculture by permanent settlement and elimination of the long fallow. Under these conditions the vital problem of crop rotation arises.

Erosion destroys more mineral reserves and organic substance than the growth of crop. Crops should therefore firstly be considered from the point

of view of the ease of action they allow the causal factor of erosion. It is necessary to alternate clean cultivation and protective covers, but the question of restoring nutrient elements must also be considered.

Fertilisation undoubtedly remains the vital method of maintaining soil fertility. However, mineral fertilisation is expensive and, alone it is not sufficient to restore lost fertility to the soil. It must have an organic support. The ideal organic fertiliser is farmyard manure, but its production and use is not yet widespread in Africa.

Fertilisation is now becoming more general in African agriculture but at the same time a key problem to be solved is the judicious use of vegetation to determine crop rotations which comply with the requirements of modern Africa and also with the need for soil conservation.

(1) Cover Crops

One of the first means of solving this problem is to be found in the use of cover plants. Their role is to cover the soil and protect it from attack by water. They can be used in space, i.e. to cover the area of ground left bare by the main crop, or in time, i.e. in rotation with crops to provide periods of effective protection and regeneration. The main cover crops are grasses and legumes which provide a dense cover. Table XXXII clearly shows their role in reducing erosion: there is in all cases a considerable decrease in soil loss in comparison with results on bare soil. But the same Table also provides certain indications which should always be taken into account.

(1.1) Effect of cover density. This effect was mentioned earlier but should be recalled here. Table V shows that the denser the cover obtained, the greater the protective role of a cover plant.

(1.2) Effect of rapidity of growth. Since the most erosive rains frequently occur at the beginning of the rainy season in the tropics and since at that time the environment is very susceptible to attack by water, a cover plant should cover the soil as quickly as possible. Example 3 in Table XXXII gives a comparison of the effect of a local *Pueraria* and an imported *Dolichos lablab* variety at Kindia. Both species were planted on 25 May. The former, acclimatised to the region, had already covered the soil in June, but the latter, less well acclimatised, did not provide any protection until three weeks later. The difference of 251 tons/sq. km. between the soil losses recorded under those two covers resulted from the phenomena which occurred during the three weeks' interval.

Example 5 is further proof of the same fact. Bengal hemp is a slow-growing legume while *Pennisetum* is a fast-growing grass. In addition Bengal hemp is often sown late. Consequently, although it provides some protection, it is less effective than *Pennisetum*.

(1.3) Effect of sown cover compared with natural vegetation. It appears that the cultivation of a cover, because it involves some tilling of the soil at a critical period, allows more erosion to occur than under dense

natural cover. Example 7 in Table XXXII shows that erosion on natural protected pasture is only three-fifths that on cultivated pasture. Nevertheless, once a cover crop is established, it is effective.

Table XXXII.—Effects of cover plants on run-off and erosion in Africa south of the Sahara

Year	Crop	P (mm.)	R (%)	E t/sq. km./annum
	1. ORSTOM Centre at Adiopodoumé (Ivory Coast). Slope: 7%			
1956	Bare soil	1,939	23·6	11,770
,,	Bengal hemp sown flat	,,	14·4	4,787
,,	*Flemingia* sown flat	,,	12·9	4,250
1957	*Flemingia* cut back (second year)	2,383	1·2	14·3
,,	Bare soil	,,	32	10,447
	2. Sefa (Senegal). Slope: 1 to 2%			
1954–63	No cover (average for seven years of this period)	1,201	40·1	2,313
,,	Sorghum green manure (average for nine years of this period)	1,157	20·6	782
,,	Natural fallow (average for seven years of this period)	1,203	16·6	488
	3. Kindia (Guinea). Slope: 6%			
1956	Citrus on bare soil	1,342	9·4	1,787
,,	Citrus plus *Dolichos lablab*	,,	2·1	562
,,	Citrus plus *Pueraria*	,,	2	311
	4. Mazoe, Henderson Research Institute (Southern Rhodesia)			
1953–54	Bare soil	917·2		61·5 t/acre
,,	Bare soil protected by gauze	,,		0 ,,
,,	*Digitaria*	,,		2·9 ,,
1954–55	Bare soil	1,129·2	48	225·8 t/acre
,,	Bare soil protected by gauze	,,	6	0·9 ,,
,,	*Digitaria*	,,	8	0·3 ,,
1955–56	Bare soil	907·8	41	60·1 t/acre
,,	Bare soil protected by gauze	,,	1	2 ,,
,,	*Digitaria*	,,	2	0·1 ,,

Year	Crop	P (mm.)	R (%)	E t.sq. km./annum
	5. Mazoe, Henderson Research Institute (Southern Rhodesia)			
1953–54	Bare soil	917·2		61·5 t/acre
,,	*Crotalaria juncea* (Slope 6%)	,,	40	23·4 ,,
,,	,, ,, (Slope 4·5%)	,,	27	7·5 ,,
,,	,, ,, (Slope 3%)	,,	31	5·9 ,,
,,	*Pennisetum purpureum* (Slope 6%)	,,	8	1·4 ,,
,,	,, ,, ,, (Slope 4·5%)	,,	14	1·7 ,,
,,	,, ,, ,, (Slope 3%)	,,	3	0·4 ,,
1955–56	Bare soil	907·8	41	60·1 t/acre
,,	*Crotalaria juncea* (Slope 6%)	,,	19	7·6 ,,
,,	,, ,, (Slope 4·5%)	,,	20	3·5 ,,
,,	,, ,, (Slope 3%)	,,	12	1·5 ,,
,,	*Pennisetum purpureum* (Slope 6%)	,,	2	0·7 ,,
,,	,, ,, ,, (Slope 4·5%)	,,	2	0·9 ,,
,,	,, ,, ,, (Slope 3%)	,,	0·25	0·3 ,,
	6. Nanokely (Ankaratra, Madagascar). Slope: 12%			
1958–59	Sown onion-grass (first year)	1,592	20·3	17·60
,,	Onion-grass (second year)	,,	14·3	100
,,	Lupin green manure	,,	22·9	2,140
1958–59	*Melinis* pasture (first year)	991	13·9	950
,,	*Melinis* pasture (second year)	991	1·2	13
	7. Glen (South Africa). Slope: 5%			
Average 18 years	Established pasture		4·6	0·25 t/acre
,,	Protected pasture		2·7	0·01 ,,
,,	Heavily grazed pasture		5·8	0·25 ,,
,,	Moderately grazed pasture		4·4	0·07 ,,
,,	Pasture grazed and burned		12·2	0·49 ,,

(1.4) **Effect of the duration of the cover.** For the reasons given above allowance is made for erosion occurring in the year in which a cover crop is sown, while the plant is getting established. The faster the cover crop grows, thus providing more continuous cover, the less opportunity there is for erosion. But if the crop is maintained for a second year erosion processes at the start of the rainy season are controlled and erosion is considerably reduced. At Adiopodoumé (Table XXXII, example 1), *Flemingia* reduced erosion on bare soil by two-thirds, but in the second year soil loss was 700 times lower. At Nanokely (example 6), erosion in the second year was 176 times lower than in the first year under onion-grass and seventy-three times lower under *Melinis*. Two, if not three, consecutive years of cover crops are therefore much more valuable than one

in regions very susceptible to erosion. This is an important fact and must be taken into account if effective crop rotations are to be established.

(1.5) The effect of management and utilisation of cover crops. Cover crops provide a very effective method of counteracting erosion. They are also a means of regenerating the soil since they affect its properties, particularly its physical properties (structural stability, permeability, etc.). Grasses have the greatest effect in this respect. But from an economic viewpoint attention has been given to their use for purposes other than soil conservation and regeneration. Stock-raising can be combined with crop growing, and under such circumstances the livestock load becomes a factor affecting pasture effectiveness in preventing erosion. Overgrazing causes serious discontinuity in plant cover and facilitates the erosive action of water. Example 7 in Table XXXII shows that a protected pasture loses 0·01 tons of soil per acre, the same pasture moderately grazed loses seven times as much while overgrazing increases erosion twenty-five times.

As regards pasture management, the practice of burning off requires great attention. It is used to dispose of old stubble or grasses which have not been eaten and to regenerate pasture after rain. But after burning, run-off and soil loss increase. At Glen (example 7, Table XXXII) they were twice those on overgrazed grasslands. At Madagascar (Ampamorehana) run-off is said to have been increased tenfold by burning. Therefore this practice must be used rationally and a fast-moving fire is preferable to one which burns the vegetation more thoroughly.

(1.6.) Effect of species used. The extensive research carried out shows that grasses or grass-legume mixtures with a cumulative effect are more effective than legumes alone.

(2) Green Manures

Research into soil conservation by biological means has shown the vital part played by cover crops. They protect the soil and give it increased resistance. But in view of the need to improve the soil properties and in the face of the problems involved in fertilisation in Africa, agriculturalists have studied the effects of incorporation of cover crops and of vegetation in general. This practice provides the soil with organic substances which should improve its physical properties. It also returns to the soil the chemical elements contained in the plants.

The practice of green manuring is still much controversed as regards tropical and Mediterranean regions. Although some agronomists have obtained encouraging results, the reverse is true of others. The first results obtained in Africa are as follows:

At Adiopodoumé (Ivory Coast), a cover of *Crotalaria usaramoensis* was incorporated in February 1957. A crop of yams on ridges followed. The yams were planted in May and grew normally until July. Taking the overall figures, erosion under yams was less severe than on bare soil. However, a detailed study shows the following results for run-off and soil loss for two periods running from 18 May to 11 June and from 12 June to 10 July.

18 May–11 June		
Run-off as % of rainfall	Yams on green manure . .	6·9
	Bare soil	30·3
Erosion in tons per sq. km. . . .	Yams on green manure . .	332·1
	Bare soil	3,740
12 June–10 July		
Run-off as % of rainfall	Yams on green manure . .	31
	Bare soil	43·8
Erosion in tons per sq. km. . . .	Yams on green manure . .	3,936·1
	Bare soil	3,862·9

It is therefore clear that the action of the green manure on the soil facilitated the infiltration of water at the start of the rainy season after it had been ploughed in. At that time, run-off was greatly reduced compared to run-off on non-protected soil. Consequently soil loss was also reduced, viz. it was ten times lower than on bare soil. But this state of affairs soon changed and results subsequently showed a disastrous similarity

The effect of ploughing in green manure (it should be specified that the soil was sandy) was therefore merely to delay the start of run-off and erosion during the following rainy season, but the additional resistance imparted to the soil was of a very temporary nature.

At Sefa (Senegal) in 1955 sorghum green manure was tested in comparison with fallow and then in 1956 the effect of both these covers on a groundnut crop was measured.

In 1955, run-off and erosion were higher under green manure than under fallow, viz. 21·6% compared with 9·5% and 1,420 t/sq. km. against 977 t/sq. km. It is striking to note that before being dug in the sorghum had allowed a soil loss of 1,130 t/sq. km. whereas loss from fallow was only 922 t/sq. km. for the same period. That means that soil loss after the sorghum was ploughed was 290 t/sq. km. while during the same period loss from the fallow field was only 55 t/sq. km. This difference is largely explained by the fact that mechanised ploughing in of green manure makes the soil less resistant. The rains which follow ploughing in of green manure erode the soil more easily. This raises the problem of the best time for turning in green manure; the most favourable period appears to be the very beginning of the dry season.

A study of the run-off and erosion occurring under a groundnut crop after sorghum green manure and after fallow, shows that fallow had the better effect, viz. run-off of 14% of annual rainfall compared with 16·8% and erosion of 382 t/sq. km./annum compared with 433 t/sq. km./annum. On the other hand, green manure has a more marked effect on yield: 1,948 kg./hectare of groundnuts after turning in sorghum compared with 1,748 kg./hectare after fallow. This shows that green manure has some economic advantage despite the disadvantages it may present from the pedological point of view.

Similar results were obtained at the Nanisana Station in Madagascar. On red ferrallitic soil, the following annual soil losses and run-offs were recorded (average of five years) for three rotations:

(*a*) Groundnuts—green manure—manioc—fodder crop
E (t/sq. km./annum): 1,560; R (%): 9·6
(*b*) Groundnuts—green manure—maize—fodder crops
E (t/sq. km./annum): 1,210; R (%): 8·3
(*c*) Groundnuts—temporary pasture of *Chloris gayana*
E (t/sq. km./annum): 770; R (%): 6·9

On yellow ferrallitic soil, the same three rotations gave the following results:

(*a*) E = 1,550; R = 9·4
(*b*) E = 1,100; R = 8·1
(*c*) E = 600; R = 5·9

In that experiment too, grassland proved better for soil conservation purposes than green manure.

Thus the effect of green manure appears to be inconclusive as regards soil conservation in Africa. On the other hand, it has a beneficial effect on yields. But the measurements obtained are too fragmentary (inadequate range of climates, soils and plants) to allow reliable conclusions to be drawn at the present time.

(3) Rotations

Research into the rôle played in soil conservation by the various crops shows that their sequence may be considered from the angle of soil and water conservation as well as from an agronomical point of view. Though soil and moisture losses occur in the presence of rotations these latter can be planned so that the average annual figures for run-off and erosion remain within tolerable limits.

Obviously local conditions (climate, soils, crops, land suitability) will guide the choice of rotations for conservation purposes. No general recommendations for useful rotations can therefore be made, but the principles for establishing them can be based on what has been said above.

* * *

The problem of soil conservation is neither new nor confined to Africa. However, the findings obtained over the past fifteen years in various parts of Africa have drawn attention to this problem, which is of vital importance for the future of the countries concerned. Research has been carried out and from the results a number of facts necessary for the establishment of a rational development plan have emerged, but the conclusions drawn are still incomplete. The final results of more extensive research should provide a more coherent collection of data from which useful lessons on soil conservation and development in Africa can be learned.

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COLONIAL EXPERIENCE

Stockdale, F. 1937. Soil erosion in the colonial empire.
Empire Journal of Experimental Agriculture 5(20):282-297.

The problem of soil erosion in the Colonial Empire is not a new one, but it must be recognized that the rate of erosion has been greatly accelerated by the increased development in recent years, and is assuming serious proportions in certain parts of the East African dependencies. Here it is found that erosion is worst when the rainfall is relatively low and the rainy season is heralded by numbers of heavy rain-storms. When they occur the land is as dry as dust with a poor cover of vegetation. The absorptive capacity of such soils is low and considerable quantities of top soil are washed away before it becomes thoroughly wetted. When the rainfall is more evenly distributed, even though it may be more heavy, erosion is not so bad as in areas where lengthy dry periods occur. Lands under conditions of an evenly distributed rainfall also retain a vegetative cover better than do lands which are liable to periods of drought.

Some soils erode more severely than others. The calcareous soils of Jamaica, for example, do not erode at all seriously, whilst those derived from schists in the Blue Mountain Range readily are washed away with a fall of rain. Soils in the drier areas of Kenya with a high silica ratio erode more rapidly than the loams to be found in the wetter areas. The lighter sandy lands of St. Vincent also erode more easily than do the heavier lands of its neighbouring island Grenada.

Certain loams have, in fact, a higher absorptive capacity than sands, and it is known that soils which are inclined to swell and become sticky when they are wetted erode more rapidly than soils which 'walk clean' after rains. Friable soils with a low silica ratio are not usually subject to a high degree of erosion, whilst some soils, such as those of Nyasaland, are liable to compact and form sub-soil pans and crusts from which the top soils are readily washed away.

In pastoral areas overtrampling by stock is often as responsible for erosion as overgrazing, especially during the dry season and in the neighbourhood of watering places. This trampling of dry soil, especially when sheep and goats are numerous, reduces it to powder, which is either blown away by the wind or washed away by the first rains from the layers of consolidated soil below it. The availability of water-supplies is of importance in pastoral areas as the movement of stock to and from water is often a prominent causal factor in erosion. Where water-supplies are poor, concentrations of stock occur around them, and when the grasses 'spring' after the first rains they are ravenously devoured. No satisfactory growth of grass is permitted to take place, and there is in consequence nothing to bind together the loose powdery soil and to prevent it from being eroded by either wind or water. In certain areas there is definite overstocking. This occurs in some of the East African territories in certain areas, but it is possible that the damage may

often be mitigated by an increase of water-supplies and by the adoption of controlled grazing.

Basutoland offers an outstanding example of unchecked soil erosion. The position is clearly set out in Sir Alan Pim's report, where it is recorded that the primary cause was overgrazing, leading to the destruction of the vegetation which holds the very friable soil together. Steps have been taken to adopt control measures and the position is being improved. The experience gained in Basutoland should be of value to those who are faced with problems of a similar character in East Africa.

In Ceylon, the alienation of Crown Lands above the 5,000 ft. contour has been prohibited for over thirty years, and in some of the West Indies similar legislation is in force. In St. Vincent, for example, all Crown Lands of 1,000 ft. or over have been protected since 1912 from any act which would be prejudicial to the conservation of the forests growing on them, whilst in St. Lucia lands of 1,500 ft. and over, and in Montserrat at heights ranging from 700 to 1,000 ft., have been similarly protected since 1916 and 1932, respectively.

This system of protecting the forest-cover at the higher altitudes has much to commend it in the hilly wet tropics, but it is not really effective unless it is strengthened by measures designed to protect the catchments and springs of the principal streams, and to compel, as has been accepted in Java, that where sloping forest lands are cleared for agricultural purposes there should be established adequate anti-erosion measures before planting begins.

Such measures must be framed with due regard to the soil type, the rainfall and its distribution, the slope of the land and the aspect of the slope. They should aim at checking the velocity of the 'run-off' and, if possible, at increasing the absorptive capacity of the soil. In the state of nature an equilibrium becomes established so far as run-off is concerned, but with the arrival of man and his domestic animals this balance is upset, gradually at first, but ultimately at an ever-increasing rate as the population and numbers of stock increase and developmental activities expand.

During the past few years there has been an awakening throughout the Colonial Empire to the losses which are being occasioned by soil erosion and to the threat of danger for the future. The position at the present time is briefly reviewed below.

West African Dependencies

Little or no special attention has been given to soil erosion in West Africa. Over vast stretches the land is gently undulating and the individual farming operations are on a small scale. Many of the methods of cultivation are based upon custom and are designed to check erosion. This applies particularly to the Southern Provinces of *Nigeria*. The land is often thrown up into mounds, frequently with the inversion of the top layer of soil, so that the weed- or grass-vegetation which it carries is buried. This helps to hold the mound together and the presence of these mounds checks the flow of rain-water and allows it to soak in. Throughout West Africa in the yam-growing areas the system is much

the same, but in some places ridges and furrows are made and these are so broken that run-off is checked. The local hoes are specially adapted for making mounds or ridges and for inverting the top soil. Where the rainfall is heavy the mounds or ridges are quite large and their preparation involves much labour.

Mixed cultivation is also the rule, and where it is practised there is rarely any lengthy period when the land is devoid of any form of vegetation. In the drier areas towards the north, however, the ridges are smaller, and during the dry season there is little vegetation on the land.

The Department of Agriculture in Nigeria has found, as the result of experimental tests, that the system of mound- or ridge-cultivation is sound and that in the Southern Provinces there is little erosion provided that vegetation is continuously kept on the land by systems of mixed cultivation or rotations. In the Northern Provinces, the position is not so satisfactory, but generally speaking there is little erosion resulting from agricultural operations except where populations are concentrated and stock numbers are high. Where ploughing has been introduced care has been taken to introduce only the double mould-board pattern so that ridge-and-furrow cultivation is continued. Ploughing also is only used where mixed farming is practised and farmyard manure is prepared for use on the land.

In the extreme north, increases in the population and their stock are resulting in encroachments on the scanty forest-cover and Prof. R. Stebbing has drawn attention to what has frequently been referred to as the advance of the Sahara into Nigeria. On examination it has been found that it is not a case of encroachment by drifting sand from the Sahara, as had so often been mistakenly supposed, but one of soil degradation, which has led to the establishment of desert conditions in areas previously protected by vegetation. Repeated use of the land for agricultural purposes has reduced the density of the vegetation, and grazing by large numbers of stock has helped in the destruction. Prof. R. Stebbing, referring to the increase of population in a recent paper, states: 'Some change in the methods of agriculture would appear imperative if a farther migration to the south is not imposed upon it. Here the agricultural use of the forest is accompanied by the browsing and grazing of large herds of cattle and flocks of sheep and goats. Here again the numbers of animals are said to have greatly increased during the last two decades.' The desert conditions are being developed *in situ*, and a special officer has been entrusted with the task of co-ordinating the measures needed to prevent a spread of the damage. A certain amount of erosion both by water and wind occurs in the area, but this is not as responsible for the damage as the general soil degradation which is taking place.

The general position in the *Gold Coast* is not as satisfactory as that in Nigeria. Vast areas of high rain-forest have been cleared for food farms and for cacao cultivation. It is estimated that there are over a million acres under cacao, and although no special measures have been taken to prevent erosion, the losses have not been so great as might have been expected, owing to the stumps of forest trees having been left in

the clearings, and to the establishment of the cacao in a mixed plant-cover of food crops. Many of these crops are grown on mounds, and where this system of cultivation is practised the soil losses from erosion are not excessive. There have been, however, considerable areas of forest cleared for cultivating maize, which is the staple food crop in the Gold Coast. In many of these areas erosion has developed and it is now common to see large areas of land devoid of its surface-layer. This is particularly noticeable in the coastal areas where the population is dense and a fair amount of erosion is also noticeable in areas where the population has increased considerably during the past twenty years.

In the Northern Territories of the Gold Coast stock numbers have been increasing since rinderpest has been controlled. The Department of Animal Health is endeavouring to demonstrate the value of cassava roots and hay as food for cattle during the dry season, whilst the Department of Agriculture is testing the practicability of introducing a system of mixed farming in those areas where the population is fairly dense. Under the existing system much of the land is being degraded and a certain measure of erosion is to be noticed.

In *Sierra Leone*, soil erosion has been responsible for serious loss of fertile top soils from the hills of the Colony behind Freetown. Many coffee and other cultivations have seriously deteriorated because no attempts have been made to terrace the land with a view to preventing soil wash under the heavy rainfall of the area. Attempts are shortly to be made to resuscitate some of these cultivations and to encourage the establishment of terraces and other measures designed to check erosion.

In the Protectorate the position is not so serious, for here the chief agricultural problem on the high lands is the maintenance of soil fertility. Shifting cultivation is generally practised for the production of hill rice, millets, and other food crops, and land which was formerly under good forest is now covered only with bush-growth and in many areas with a poor cover of grass. There is naturally a certain measure of soil washed into the swampy valleys which intersect the undulating hills, but increasing attention is now being given to the cultivation of rice in these swamps and it is expected that the pressure on the high lands will thereby be reduced.

In the *Gambia*, the agricultural methods are based on the ridge-and-furrow system, and a special hand-implement has been devised for working the light sandy soils and for inverting the top soil layer when the ridges are being made. In consequence soil erosion is not serious, except occasionally on the edges of the creeks.

East African Dependencies

In the East African Dependencies the picture is very different. Uncontrolled erosion is visible in many places and gully-erosion at its worst can frequently be seen. Hill slopes formerly fertile are becoming barren wastes, and plains, which were formerly grass-covered, are now being ruined.

In *Northern Rhodesia*, the earlier European pioneers paid little or no attention to soil erosion on the lands which they brought into maize or tobacco cultivations. In recent years, however, a certain amount of

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ridge-terracing has been introduced. The Ecological Survey has recently shown that there have been marked changes in the agricultural systems used in the Reserves, especially in those nearest to the European areas. The older and traditional native systems of agriculture consisted of small farms of 2–3 acres in extent. These were cut out of the bush, with tree stumps left here and there, and the formation of mounds for certain of the crops grown was the common practice. Within the past twenty years ploughs have been introduced, and during this period there has been a piecemeal departure from the traditional systems of agriculture towards an imitation of the methods of European farmers. Areas of 10–20 acres have been cleared and stumps removed so that the land may be ploughed. Often the ploughing has been done up and down the slope, whilst maize and the larger millets have taken the place of finger millet, and sweet potatoes, instead of being planted on mounds, have been grown on the flat. Ploughing has tended to increase the run-off and there have been no tree stumps or mounds to check the flow of water. Soil erosion is, in consequence, becoming more and more serious and unless a change can be effected serious damage must result. It is not to be expected that a reversion to the traditional methods of the past will be either possible or practicable, and the efforts of the Department of Agriculture are directed towards demonstrating the importance of anti-erosion measures, ridge-and-furrow cultivation along the contours, and mixed farming.

In certain of the pastoral areas of the territory, increasing numbers of stock are giving rise to a greater destruction of forest-growth than is desirable, and some overgrazing and overtrampling of pasturage is noticeable. With an increase of the water-supplies in the native stock areas and a better organization of stock marketing a considerable improvement could be effected.

In *Nyasaland* increased attention has been given of late to the problem of soil erosion. The earlier records show that the inhabitants of the country lived almost entirely in the alluvial valleys and plains bordering on the rivers and lakes. At that time the plains were reputed to be extraordinarily fertile. The hills and mountain ranges were forest-covered and many of the streams from the hills ran throughout the year. Areas at present sparsely populated, with little or no water in the streams, are reported to have been well wooded fifty years ago, with streams flowing for practically the whole year round. Large forests have given way to open woodland or orchard country consisting of tall grass with scattered small trees, and this orchard country, in its turn, is giving place in certain areas to pure grassland. In fact, treeless plains now extend over considerable areas of the country and mountains and hills stand up as large masses of bare rock. Important waterways, such as the Shire, have silted up and much of the earlier rich alluvium has been lost. It has been computed that many of the highland areas are losing soil at the rate of a quarter-inch layer per annum, whilst bush fires, which rage at the end of the dry season, are contributory to the destruction.

Such is the picture of the changes which have taken place in Nyasaland, and that grave concern is felt is not surprising. The soils of Nyasaland

are very friable and, in consequence, erode easily. Sub-soil pans and crusts are common, and these in their turn encourage erosion as the absorption capacity of the soil is reduced.

In the tea cultivations greater attention is being given to the growth of cover crops, and the adoption of anti-erosion measures is becoming general. On tobacco and cotton lands a system of broad-based contour-ridges, graded according to the slope of the land, has become common. The Government has also adopted special legislation (Ord. No. 15 of 1932) to control bush fires, and has seconded a Forest Officer for special soil erosion duties. His chief work will be in connexion with the development programmes for the Central and Northern Provinces, where it is hoped to introduce rational systems of land-usage with clearly defined agricultural and forest policies. The recent agricultural survey has emphasized the necessity for care in the development of these areas, so that future generations in Nyasaland will not be faced with large losses of valuable land and an inevitable costly expenditure on anti-erosion works.

Passing from Nyasaland into *Tanganyika*, the damage which can be caused by soil erosion can clearly be seen. Over considerable areas of the Lake Province, wind-erosion has caused much damage for a number of years, whilst in parts of Central Tanganyika gully-erosion at its worst is frequent. In yet other areas, concentrations of stock have been responsible for overgrazing and for excessive trampling.

Much attention has been given to the problem in recent years. A standing committee, on which the Agricultural, Veterinary, Geological, Forestry, Public Works, and Railway Departments were represented, was set up under the chairmanship of the Director of the East African Agricultural Research Station at Amani to study the problem and to make recommendations for work to be undertaken. The problem is being approached in each area according to the form in which erosion is attacking the countryside, and the work has been entrusted to the Heads of the Agricultural, Veterinary and Forest Departments acting in co-operation with the Administration. Active steps are being taken to deal with the problem by means of a multitude of minor operations, including the planting of trees to check wind-erosion, contour-ridging and terracing, contour hedge-planting, the damming of gullies, &c. These works are being carried out by local endeavour under local stimulus and supervision.

In the south, around Iringa, efforts are being made to control the annual burning of pastures, schemes of reafforestation and of planting wind-breaks have been undertaken by the Native Authorities, control of wood-cutting has been imposed and steps taken to check the frequency of forest fires. Contour-ridging and the planting of contour-hedges on cultivated lands are being encouraged.

In the Lake Province, hundreds of miles of wind-breaks have already been established, and the Department of Agriculture has greatly assisted the development of contour-ridging and terracing. Mixed farming is being encouraged, and the planting of rows of sisal around the boundaries of farms is becoming general. Grazing reserves have been set aside for stock, increased water-supplies for stock are being developed,

and the low-lying valley lands are being developed for grazing during the dry season. Settlements in new lands reclaimed from tsetse are also being established to relieve the badly congested areas.

Around Dodoma, the principal cause of erosion is the trampling of the pasturage by stock moving to and from the scanty water-supplies. Watering places for stock are therefore being increased and improved in this area. It has also been demonstrated at Dodoma and elsewhere that, if overgrazed or overtrampled grazings are rested for a year or two, the vegetation quickly recovers and sheet- and gully-erosion are checked.

Efforts are being made to establish settlements in the plains so as to allow the upland pastures a chance to recover. In both the Central and Northern Provinces of Tanganyika, concentrations of population are to be found on the hills. In the times of raids there were definite migrations to the hills for safety, and permanent settlements were established thereon. In recent years, the Department of Agriculture has carried out valuable demonstrations of anti-erosion measures in the hill districts, and the majority of the Native Authorities have passed rules making anti-erosion measures compulsory. Clearing or cultivation on steep slopes is prohibited, contour ridges or hedges have to be provided, and the cutting of wood and grazing of livestock in controlled riverside areas have been prohibited. The anti-erosion legislation by the Chiefs is an important step forward; it has the full support of the Chiefs, the elders, and the people themselves. It is a tribute to the work of the officers and instructors of the Department of Agriculture in their efforts to educate public opinion and to interest the native authorities in the preservation of their lands from ruin. The movement of hill tribes to the plains is also being encouraged, but this movement can only be gradual, because when the hill people take up habitation on the plains they often suffer severely from malaria, and they have a real fear of the damage to crops on the plains by game.

The Department of Agriculture has, however, recently undertaken the organization of a number of settlement schemes, each based upon an experimental station and an instructional centre. Careful attention is being given in all these settlements to the adoption of anti-erosion measures and to the encouragement of mixed farming.

Anti-erosion propaganda is also being carried on through the schools.

Much useful work is being done in Tanganyika, and if the present measures are prosecuted with energy a great improvement in the position will be effected within the next ten years. There is ample land available, as four-fifths of the territory is still infested with tsetse, and it has been demonstrated during the past few years that land can be won from tsetse either for organized settlement or for the extension of grazing for stock.

An investigation of water-supplies has also been undertaken, and the possibility of extending irrigation has been studied. On the slopes of Kilimanjaro much erosion is still caused by inefficient irrigation, and if an improvement equivalent to that which has taken place during the past five years in the coffee-growing areas of the mountain can be effected, the position will be greatly improved.

In *Uganda* the soil-erosion problem has not been given such wide-

spread attention as it has been in Tanganyika. The damage which might be caused by erosion became evident when a certain area of the Serere Experiment Station in the Eastern Province was found to have suffered so severely from sheet-erosion that after twenty years little surface-soil was left. The area had been eroded to the sub-soil, which was practically unproductive despite the efforts made to maintain fertility by the use of green manures. This example forcibly directed the attention of the Department of Agriculture to the need of encouraging agricultural methods designed to ensure the maintenance of soil fertility. Experimental tests have demonstrated that soil fertility can be maintained in the elephant-grass country by the rotation of cultivations with resting periods of two to three years under elephant grass. It has also been found that coffee cultivations can be saved from soil erosion if mulches of elephant grass or banana trash are used on the contours. An extension of this practice is gradually taking place, but there are still many coffee cultivations on the hill slopes in which anti-erosion measures have not yet been taken. There are also in the Buganda Province areas of hill lands which have been put into cotton with the resultant loss of fertile top soil.

In the Eastern Province, where the dry season is often very severe, rotations of cultivation with resting periods under grass are being tried, but it is probable that a system of mixed farming and broad-base contour-ridges will have to be introduced if the sheet-erosion from which considerable areas of the Province suffer is to be checked.

An Agricultural Survey Committee was established in 1935 to deal with soil-deterioration problems, and to analyse the *mutala* surveys which were being undertaken. These surveys were designed to secure data about the social life of the people, their dietary, and the acreages under crop during the long and short rains. Data concerning the average size of the holdings, the rotations practised, and the areas available for arable cultivation and for pasturage, have been secured. Much information of value has been accumulated, and in certain densely populated areas in the Eastern Province sheet-erosion has been found to be serious. Its development has been encouraged by the use of ploughs, without the adoption of mixed farming, and by a reduction of the resting-period when the land is under grass. Erosion often begins from the rocky outcrops, which occur frequently in the Province, as it is from these that water-flow starts during the tempestuous storms that commonly occur with the break of the rains. Definite anti-erosion measures will have to be adopted if the sheet-erosion which is taking place is to be checked, and mixed farming will have to be introduced in those areas where there is an insufficient amount of land available for the necessary resting-periods between cultivations.

A soil-erosion inquiry has been made by the heads of the Geological and Forest Departments, and their report has recently been issued. Attention is drawn to the serious erosion which is taking place in the north of Uganda, and it is clear that large areas will have to be retired into reserved forest if the grazing and agricultural lands are to be saved from ruin. Attention is drawn to the extent of the sheet-erosion in the Eastern Province. Losses are also occurring in the Buganda Province and elsewhere where cotton and coffee cultivations are being carried out

on hill slopes without the adoption of anti-erosion measures, such as contour-ridges, strip-cropping, contour-mulchings, &c. In certain areas, overgrazing is causing some trouble, and greater attention will have to be given to the spread of the stock population by an increase of water-supplies and to the introduction of rotational grazing.

Except in the north of Uganda little gully-erosion is to be seen, but danger from the insidious sheet-erosion exists. Its widespread effects are only now being realized, and unless definite action is taken soil deterioration will progress and lower crop-yields result. Cotton yields are already falling in certain areas of the Buganda Province, and there has recently been some loss of quality. These effects are probably the result of soil deterioration and much of this, especially in the hilly areas, is due to sheet-erosion.

In *Kenya* the position is much more serious. It is the most important land problem with which the country is faced at the present time. It is impossible to exaggerate the gravity of the problem. There is little doubt that soil erosion has been extending in recent years in some of the Reserves, and whilst reconditioning has been started in certain areas and the results which have been obtained show that erosion can be checked, measures of wider application will have to be undertaken without delay. It is possible to save the greater part of the areas affected if prompt action is taken.

In the European areas in the highlands, much has been done in the past few years. Broad-base contour-ridges have been made over extensive areas and strips of grass or other close-growing vegetation have been established. In coffee cultivations, greater attention has been given to the use of cover crops, shade, and box-terraces. The Agricultural and Land Bank is playing an important part in the development of anti-erosion measures on European holdings, as general advances are not issued to proprietors who do not adopt adequate measures to conserve the top soil. Provision has also recently been made for special advances for soil-erosion work to be made on the security of crops. In several areas the position is reported to be satisfactory but in others there is still much to be done. On the Plateau greater attention to soil erosion is necessary. The problem is largely one of finance in the European areas, as the settlers are now fully alive to the dangers to their lands from erosion. Special power plant for the construction of broad-base contour-ridges will be required if the work is to be hastened, and in some areas a greater measure of afforestation may have to be undertaken.

Bad erosion may be seen in parts of the North, Central and South Kavirondos, the West Suk, Elgazo, Kamasia, Samburu and Kamba Reserves. In the lower areas of Fort Hall and Embu, and in Kitui, there are some bad patches, whilst a certain degree of erosion is also to be seen in other areas, such as parts of Central Kavirondo and Kajiado. The Kamba and Kamasia Reserves probably present the most depressing pictures, and it is estimated that in the former over one-third of the total area (1,000,000 acres) of the Reserve is showing signs of erosion. Some very bad gully-erosion is to be seen in both Reserves.

The causes of the erosion in the Reserves are many and varied. Basically, they are due to the removal of the vegetation-cover and the exposure of the soil to the effects of the rain and the wind. This may have been brought about by the denudation of steep hill-sides of their forest-cover, by the practice of shifting cultivation on hill-sides without the use of anti-erosion measures, such as strip-cropping and contour-ridges. Grass fires, overgrazing, and the creation of cattle tracks by stock travelling to water and excessive stock populations, especially of goats, all play their part. Taking the Reserves in Kenya as a whole, cultivations are as responsible for erosion as is overstocking or overgrazing. In Masailand, which is purely pastoral, there is little serious erosion, but in the hilly reserves cultivations have given rise to much erosion directly, and also indirectly, through the reduction in the area and quality of the grazing. In these circumstances, overstocking has resulted and overgrazing has become serious. If the cultivations were reduced and rotational grazing practised the damage from overstocking would be lessened. The whole problem in these areas is to secure a satisfactory balance between agricultural and pastoral activities, and this is not likely to be achieved except through an intensification of agricultural methods or a reduction in stock numbers, or a combination of both.

In the Kamasia Reserve the damage is largely the result of the lack of adequate water-supplies for stock. This leads to the concentration of stock on the limited water-supplies, with soil damage caused by over-trampling and overgrazing. Stock-tracks between the water-courses also frequently develop into gullies. If the water-supplies could be augmented and the stock population spread throughout the whole Reserve with provision for rotational grazing, there would be less damage. There are areas, however, where the stock population is in excess of the grazing available, even if the water-supplies were augmented, and in these areas the reduction of stock numbers, and especially of the numbers of goats, will have to be contemplated if the countryside is to be saved. In the Kavirondos, the greater part of the erosion is caused by agricultural activities unaccompanied by the adoption of anti-erosion measures, and if soil deterioration is to be checked the introduction of animal husbandry into a system of mixed farming is desirable.

Reconditioning has been started in the Kamasia and Kamba Reserves. In the former 20,000 acres have already been dealt with, and it has been demonstrated that land retired from grazing can be covered in two or three years with a good cover of permanent grass capable of carrying limited numbers of stock. No goats have been permitted in the reconditioned areas and proposals for limiting the grazing of goats to defined areas in the Reserve are now under consideration. The construction of dams for the provision of additional water-supplies has already begun. In the Kavirondos, the Central Province, and the Kamba Reserve, the Department of Agriculture has laid down a number of demonstrations in the agricultural areas to illustrate the value of contour-planting of elephant grass, contour-ridging, stagger-trenching, &c. Reafforestation has also received attention but more work in this direction is necessary if steep lands and natural drainage channels are retired, as they should be, from agriculture or pasturage.

Sufficient has been indicated above to show that, whilst the problem is a serious one, it is dangerous to generalize as to the steps which should be taken to effect a cure. The basic cause or causes of the trouble must be determined in each area before remedies are decided upon. Anti-erosion works and reconditioning on a large scale will be needed, but these are unlikely to be of lasting effect unless efforts are made at the same time to improve the methods of agriculture and animal husbandry. The efforts made will require the co-operation of all branches of the Government service and the problem will have to be tackled on a wide front. Social and economic factors will have to be considered, as well as the technical issues which concern the Agricultural, Veterinary and Forest Departments. The Standing Board of Economic Development has recently undertaken to survey the position and has secured the services of an Agricultural Officer for this purpose. The Native Authority Ordinance has also recently been amended to provide that measures can be taken for dealing with soil erosion when necessary, and for the prevention of fires in the forest areas in Native Reserves. An attempt is also being made, through propaganda, to educate the people to the losses they may suffer if their lands are not conserved. Soil conservation has been, in fact, placed first on the list of the extension work of the Department of Agriculture in the Native Reserves, and useful assistance in propaganda work is being received from the Kenya Arbor Society.

Soil erosion in the Reserves has been gaining ground in recent years, but the position is one which can still be met if it is tackled on a wide front, and if the necessary measures are supported by determined efforts to improve the methods of agriculture and animal husbandry used by the peoples concerned. To provide for the one without the other would be futile, for within but a few years the position would become serious again, if the people were not to be condemned to economic and social stagnation.

Somaliland.—It has been evident of late that the pasturage for stock has been seriously deteriorating, and this has been confirmed by a series of aerial photographs. Uncontrolled grazing is leading steadily to destruction of vegetation and to increase of erosion. It has been demonstrated that a system of deferred grazing will enable the pasturage rapidly to recover, and the Government has enacted legislation which enables district officers to control grazing and to prohibit it in certain circumstances until after the grasses have flowered and seeded. This system, provided it is applied over wide areas, is likely to be effective, but the closure of areas to all grazing may have to be introduced in certain cases. The position in Somaliland is not at present as serious as in some other parts of Eastern Africa, and it is expected that the legislative measures now available will produce a great improvement within a few years.

Conclusion

An attempt has been made to survey the present position in regard to soil erosion in the Colonial Empire, to describe the measures which are being taken to check and control its effects, and to indicate where further efforts are required.

The most serious losses are taking place in East Africa, particularly in Kenya. Here the condition of some of the Native Reserves is becoming serious and deterioration is proceeding apace. It is the most important land problem which the country has to face, but if active steps are taken without delay the position can be greatly improved within a decade. The actual causes of erosion are numerous and varied, and each drainage area of any country requires close examination before plans of reconditioning or control are decided upon. Untutored agricultural operations are responsible for erosion in many parts, whilst in others concentrations of stock numbers due to a shortage of grazing or inadequate water-supplies are the chief contributory causes. In yet others, stock numbers are in excess of the carrying capacity of the land and overgrazing takes place. Rotational or deferred grazing has been demonstrated to be effective as a cure in certain circumstances, and strip-cropping, contour-ridging, and mulching have proved their value in agricultural lands. There are many instances where deforestation has been excessive, and considerable areas of land may have to be retired from cultivation or grazing if the position is to be improved.

The problem is one which must be approached from various angles. Physical, biological, and social factors have to be considered, and there is no doubt that the fullest co-operation between the administrative and technical departments is essential if advances are to be made. Generalizations as to control measures must be avoided. Each area should be examined in detail and working plans evolved before any decision is taken as to how the problem should be tackled.

Vegetation-control is the most important method of controlling soil erosion, since it produces a cure by natural methods and is much less expensive than treatment by mechanical means. In cultivated lands on hilly slopes, however, the use of contour-ridges, terraces, hedges and drains is necessary when strip-cropping cannot be adopted, if the fertile top soil is to be saved.

The use of control measures, without an improvement in the systems of agriculture and animal husbandry, is likely to be unsatisfactory. Such a policy meets only the circumstances of the present and does not provide for the future. Expenditure on anti-erosion measures should at least be matched with expenditure of a similar magnitude for agricultural education, demonstration and propaganda, if the future is to be secured.

SELECTED BIBLIOGRAPHY

In addition to references found in the annual reports of administrative officers and of Agricultural, Veterinary, and Forestry Departments, and in various Colonial agricultural journals, the following recent publications are worthy of examination:

1931. Report of the Committee on Soil Erosion, Ceylon.
1932. Land Commission of Kenya.
1934. A. J. W. Hornby, Denudation and Soil Erosion in Nyasaland, Dept. Agric., Nyasaland, Bull. No. 11 (New Series).
1935. F. A. Stockdale, Soil Erosion. Empire Cotton Growing Rev., 12, No. 1.
1935. V. A. Beckley, Soil Erosion. Kenya Dept. Agric., Bull. No. 1.
1935. A. D. Hall, Overstocking and Soil Erosion, Chap. V in The Improvement of Native Agriculture in relation to Population and Public Health. O.U.P.
1936. H. C. Sampson, Soil Erosion in Tropical Africa and Problems connected with it. Empire Cotton Grow. Rev., 13, No. 1.
1936. A. Wimbush, The Forestry Problems of the Windward and Leeward lands.
1936. A. Wimbush, Report on the Forestry Problems of Jamaica.
1937. Sir F. Stockdale, Report on a Tour to East Africa.
1937. Report of the Soil Erosion Committee in Uganda (not yet printed).

(*Received August 27, 1937*)

Hellen, J.A. 1969. Colonial administrative policies and agricultural patterns in tropical Africa. In Environment and land use in Africa, ed. M.F. Thomas and G.W. Whittington. London: Methuen and Co.

12 Colonial administrative policies and agricultural patterns in tropical Africa

J. A. HELLEN

'Agricultural development must go beyond its colonial framework' – so wrote the French agronomist René Dumont in his survey of the New Africa (Dumont, 1962). Increasingly the African states as well as the external development agencies are reconsidering these legacies, which so tenaciously influence institutions in many developing countries, and are seeking to modify or eradicate them. Rural economic development in Africa encounters many of its greatest difficulties in a single factor of development – land. But because of the complex pressures the African husbandman has to accommodate, the agrarian landscape is more than a simple expression of current allocation of means to a desired end. The belief that low productivity in the traditional sector is due to disregard of land as a capital asset has led to the erroneous view that development must follow if the situation can be altered. In consequence the morphological interpretation of the cultural landscape as an indicator of underdevelopment demands not only the evaluation of the more obvious cultural and ecological factors but also detailed investigation of colonial, legal, social and administrative determinants which can contribute to an understanding of the landscape chronology. From a methodological standpoint this approach to the inner *Raumstruktur* of the developing countries owes much to developments in the general field of landscape analysis and is considered as one of four main analytical subjects by Troll (1962; and see also 1950). If, as can be argued, agrarian landscapes in the tropics are becoming even more finely differentiated in the geographical sense, as a consequence both of population increase and of better adjustment to potential biological productivity, it would seem that aspects of colonialism as a causal factor in such areal differentiation deserve re-examination.

That the colonial powers have left an imprint on the institutions of their former dependencies is undisputed, but the relatively short duration of *effective* administration in most parts of Africa has meant that dualism persists; the co-existence of statute and customary law, of monetized and subsistence economy, of westernised élite and tribal majority is evident. Decolonization cannot realistically be taken at its face value. Furthermore, the interaction of the various metropolitan powers with the mosaic-like web

of tribes produces visible land-use patterns of subtle distinctiveness and any attempt at elucidation must reject outright the theories of economic imperialism alone. This chapter will therefore examine aspects of those circumstances and policies which are implied by trading relationships, export patterns and land-use patterns on a crude territorial basis and appear to be important in having caused significant changes of cultural landscape. Such changes will be those associated with African agricultural patterns which serve to differentiate certain classes of modification or transformation.

The independence of many states in Africa has opened up a challenging field of inquiry into this particular colonial legacy which demands early investigation if images are not to be blurred. Of particular value would be numerous sample surveys of rural settlements to provide exact details of land utilization under specific agricultural systems; it might then be possible to establish a datum line against which to study changes implicit in records of administrative and legislative action. Very often accounts of landscape change rely on oral tradition or the reports of early colonial administrators. The nature of components of the African cultural landscape, be they dwellings, field boundaries or any other man-made feature, is such that they are erased permanently by the regenerating vegetation, by the scouring rains and devouring termites.

By colonial administrative policies are to be understood those decisions arrived at in metropolis, colonial capital, province or district alike, which serve to enforce, regulate, alter, encourage or otherwise influence the population's actions or the colony's appearance and functions. Such policies may be indirectly effective by sanctioning the policies and actions of third parties whether they be commercial, missionary or of any other organization. They may lead to complete transformation of a landscape by a single crop, to the displacement of an entire tribe, or merely to construction of a contour ridge. Such policies may be put into effect by a single administrator or an army of local government personnel; they may be centrally promulgated but moulded to local conditions or they may be inflexibly applied. In all instances they express an intention to interfere, for better or worse, with the *status quo* and must record a measurable effect which is of interest to the geographer. Any resulting agricultural patterns may therefore be examined on a variety of scales subject to the availability of the appropriate detailed studies. Many will indicate substantial change arising from new crops, new techniques and new agrarian structures; others will indicate features of an induced decay or degradation and others again will demonstrate gradual adaptation from within or compensating moves from without. Few situations are likely, on close examination, to have remained substantially unchanged.

The colonial frontier, for all its evident artificiality, embraces problems far greater than the merely tribal by preserving dissimilar administrative and legal infrastructures with associated linguistic, monetary and other features antagonistic to regional economic development. But within these frontiers colonial administrative policies appear to have induced landscape change chiefly through the operation of land policy. Such policy is variously motivated and may have had direct effects as evidenced by alienation of land, encouragement or even enforcement of cash cropping or the implementation of conservation ordinances, planned peasant colonization and the like. It may function indirectly through the operation of certain fiscal or social policies and non-agricultural development and lead to such features as recruitment of alien African labour leading to displacement of indigenous peoples, as in the plantations of West Cameroon, or to the exodus of a major tribal group in response to unpopular land policies, as in the eastward drift of Mawiko peoples from Angola to Zambia. 'In African conditions', Lord Hailey has written, 'the attitude of the Administration in matters relating to land policy affords one of the most significant indications of the relations it seeks to establish with the African population' (Hailey, 1957). In High Africa, at least, the land problem has epitomized the conflict of opposing interests and appears to have provided the dynamic for the movement towards self-determination. Those colonies or protectorates which succeed in attracting and retaining a settler element seem therefore to be characterized by general problems largely unknown in Low Africa, yet the conflict probably owes its origins as much to new ideas as to racial antagonism. It is sometimes argued that any degree of development implies a change of environment. If this is so, then the agrarian reform forced on newly autonomous states by internally generated demands for higher agricultural production will necessitate the resolution of these inherited conflicts which have hitherto remained quiescent in the normal state of social and economic dualism typical of colonialism.

Land and indigenous agriculture

The effect of colonial rule on the land has been as varied as the differing European cultures would suggest. In some instances the former freedom of tribal movement has been thwarted by the designation of tribal reserves and consequent spatial restriction of numerous groups, whereas in others manifestations of tribal identity have been suppressed. Common to most colonialists, however, has been a misunderstanding of the African material and ritual relationships to land and therefore of the patterns of occupance. Confusion has arisen particularly in the interpretation of land tenure of a communal and individual sort and in the definition of land 'ownership' as such.

On their first arrival in Africa, Europeans encountered a system very different from their own and this led them to make mistakes of interpretation – by speaking of *communal* ownership they implied that every tribesman had equal rights to every part of the tribe's land and they regarded the chief as the owner of the land. In fact, as Gluckman has shown, the chief commonly acted as trustee of the land for the tribe and his ownership gave certain *rights*. Important among these were the chief's right to demand allegiance from persons using his land, to hold land not taken over by his subjects or to repossess land allocated but not used, to demand produce in tribute, to control the settlement of his people and to legislate in matters of land holding or land use (Gluckman, 1945). The system of chiefly control distinguished by the *hierarchy of estates* and typical of such tribes as the Zulu and Tswana is, however, only one of the four main systems of land holding in Africa. *Feudal* systems with landlords and tenants exist and that of the Baganda is well known. A third type may be classified as a lineage or *unilateral descent* system under which land is held by a family descended from a common ancestor, for example, among the Yoruba. A fourth type embraces those systems where residence is sufficient to invest the individual with rights over land. Throughout the great majority of diverse systems, however, runs the common feature of access to land through membership of a community; but that this community is of greater importance than the sum of its individual members has been demonstrated by de Schlippe in the case of the Sudanese Azande where 'the pattern of behaviour inherent in the customary system of agriculture constitutes the force of adhesion of the group to the natural environment' (de Schlippe, 1956).

Indicative of the gulf between the European and tribal culture is Richards' comment on the Bemba shifting cultivator in Zambia who did not 'measure land, assess its value in size or productive capacity, or conceive of this value as a figure to be permanently maintained at a given level by the expenditure of effort and capital. He views the country round him as all one unit, all accessible to him, and all ready to supply his needs' (Richards, 1939). Such attitudes were no defence against settlers or concessionnaires who took land by right of conquest, treaty or grant and who, to quote Bohannan's phrase, would have accepted the white man's pattern of an 'astrally based grid map in terms of which people are, by a legal mechanism, assigned rights to specific pieces of earth-pieces which maintain their integrity even when their owners change' (Bohannan, 1963). But if this disparity was true of some areas, and particularly of those of low density worked by shifting cultivators, it appears to have led to modification in attitudes to land values among more densely settled African peoples at an early stage and these moves towards systematic individualization of land tenure must also be considered.

The common attitude of the African community towards the question of individual land needs would be one of satisfaction if the individual could maintain himself and his family on a subsistence basis; the production, consumption and storage of food were effectively controlled until the surplus of cash crop became desirable. Accordingly, under forms of subsistence agriculture it is reasonably easy to calculate the land requirements of the 'garden family' and the carrying capacity of the land itself. Allan has expressed this in a numerical relationship of *population–land factors* under conditions of shifting agriculture (i.e. bush fallowing): land-carrying capacity is estimated in terms of the fertility of given soil types, the percentage of cultivable land, the number of gardens needed to give a complete regeneration cycle (termed the *cultivation factor*) and the mean area *per caput* under cultivation at any given time (Allan, 1949). Thus under many systems and in particular habitats *optimum* population densities are found to be of the order of two or three persons per square mile where no artificial fertilizers are used. Since over the greater part of Africa shifting agriculture is operated in thinly populated areas where rainfall agriculture is possible, this concept of optimum man–land ratios is particularly valuable in understanding field patterns. The question of the optimum size of land holding relates to the subsistence demands placed on it and the capacity of the available family labour to clear and cultivate a certain area predominantly of seasonal crops such as cereals and legumes and to a lesser degree, except locally, of perennial crops such as bananas, cassava and yams.

Exact information on the amount and disposition of land worked by any community is less easily obtained than population data for a given territory. Just as registration of births and deaths among the African population has been the exception rather than the rule, so registration of land title has been in most cases a localized and recent experimental innovation; indeed, the U.N. Economic Survey of Africa has noted that 'information on the size of holdings is lacking. Since, however, traditional farming is almost entirely dependent on family labour and primitive technology, it may be presumed that production is predominantly on a small scale – a few hectares per family' (UNO, 1959). Aerial photography may reveal relationships between the broad land-use patterns and ecological zones down to the dimensions of the landscape cells, or ecotopes which together constitute a landscape mosaic, just as a ground traverse may establish the nature of the soil, groundwater or plant communities along a catena; but however helpful these aids may be in assessing potential biological productivity, they explain little in terms of African agricultural production or productivity. In consequence, any quantitative information is drawn from a variety of local field studies in preference to the estimates of administrations. That primitive techniques impose severe limitations on the extent of land used in any

one year by the immensely varied group of 'shifting' cultivators is borne out by the roughly comparable size of holdings in many tropical countries, and in Africa a figure of about one acre per head under main crops seems reasonable on present evidence, the figure increasing over weak soils. Even where the shift to settled agriculture does occur and the high labour input of bush clearance is eliminated after the first season, total areas worked appear to rise only slightly if at all. The important next stage as far as land requirements are concerned has followed on the introduction of cash crops, and except where techniques have been improved the critical population densities have moved towards ecological imbalance of man and land (Allan, 1960).

Agricultural and associated rural settlement patterns which derive from tribal subsistence economies are not yet sufficiently well understood to support firm generalizations, although it may be noted that certain of the principles of location operate even though costs and profitability are not overtly considered. Particularly under soil selection systems of shifting agriculture, newly colonized gardens may be located at ever-increasing distances from the major settlement and necessitate the erection of temporary garden huts until the village elders decide to transfer the entire community. It has been argued that 'under adverse conditions of physical and poor technical accomplishments, a combination which betokens a low population density, the distance certain shifting cultivators shift their main abodes is very similar to the figures which have been quoted for normal, as against exceptional circumstances' (Chisholm, 1962). Whereas it may often be true that a crop zonation is to be perceived within a radius of cultivation orientated towards a single village, two highly significant factors have to be weighted: first, the ecological soundness of much of African agriculture, dependent as it is upon certain bioclimatic indicators of fertility, tends to support catenary or mosaic distribution of crops, and secondly, the psychological factor may often impel members of an established group to break away and found their own village for non-economic reasons.

Quite often the net result is a complex pattern of land use made more so by dependence on a wider hinterland, an extensive fringe belt from which forest products such as rare timbers, thatching grass, medicaments, game and other items may be obtained and which ought to be counted as integral with the over-all land requirement. It might be argued that in Africa as a whole there is a major distinction in this diversity between those subsistence economies which have existed with and without the mechanisms of exchange usually epitomized by markets. This would appear, on present evidence, to distinguish West Africa, where traditional markets were established long before European intervention, from southern and south-eastern Africa where markets have for the main part come with the

European (Hodder, 1965). The wider significance of these characteristics, which accord in part with the division of tropical Africa into *high* and *low* regions, lies in their reflection of response to external forces such as trade links along routeways and consequent specialization of production where resources, population density and the form of political organization were favourable for the development of market foci. Land under such a circumstance might appear to move increasingly towards a state in which it assumes economic as well as social and political importance for the Africans concerned and favours assimilation into the world monetized exchange economy.

Land and the Europeans

Of all the landscape features attributable to European action and influence, the cultivated crops are the most widespread geographically, and probably the most significant culturally and economically. Some plants may have arrived fortuitously whereas others have been deliberately, even forcibly, introduced and have transformed not only the subsistence sector but also formerly negative areas whether by casual infiltration of crops like maize and groundnuts or by the regimented and wholly man-made plantation landscape of sisal, tea or coffee. Unlike those of the Egyptians or Azanians, for example, the European introductions have been notable not so much for the mobility they have permitted but rather for their introduction to Africa of large-scale production of a single crop to satisfy a market demand as epitomized in commercial plantation tillage. They have set in motion great fluxes of migrants, circulating or seasonal labour rather than *Völkerwanderungen*, and they have deprived Africans in some areas of substantial blocks of land but have made possible colonization of semi-arid or highland habitats. There is no opportunity to discuss here the respective contributions of Arabs, Portuguese and later colonists, building on the indigenous crop range which has been so extended that Africa has become a major commodity producer in a few decades. But it is important to note that the introduction of such crops has had notable side-effects on relations between tribes and on tribalism itself. Administrative paternalism has tended to favour the sedentary cultivator at the expense of the once-dominant pastoralists, and the stateless group without a centralized authority at the expense of the centralized state. Within the tribe new crops demanding new techniques have often shifted emphasis from communal to individual activity and at the centre there has been decay of tribal politics and their replacement by mere tribal administration. An equally important outcome of the new cultivated crops has been the degree to which the administrative policy has aided their spread in order better to exploit land resources. In some cases this has been through compulsory native cash

cropping, in some cases by peasant settlement schemes and in some cases by the extension of European-owned and directed farms and plantations.

Europeans' attitudes to land would appear to separate into two significant categories in this context: the one concerned with their own cultural experience, the other with mercenary considerations towards land acquired in the specifically colonial context by seizure of political power. The earliest were essentially of the *plantation* type, operated for profit or prestige. Land was seen as one of the factors of production, to be exploited in association with labour, capital and the necessary technical expertise, imported as the need arose. Europe was and is an area characterized by a high proportion of land given over to agriculture, as compared with other continents, and was typified by a situation in which *property* and *contract* rather than *status* were important. The etymology of the term colony implies cultivation or habitation, but the European colony in Africa very early differentiated between colonies of exploitation and colonies of settlement, linked with motives such as expansion of trade or emigration. Following Maunier, colonization requires occupation and legislation, an element of fact and an element of law (Maunier, 1949). The quality and extent of occupation may vary considerably and the interests of the colonists show more or less importance in shaping legislation and policy locally or in the metropolis. Similarly, colonial status demonstrates a cycle of development in relations between the metropolitan country and the dependency, both passing through phases of domination, partnership and emancipation, and it is important to view changed patterns of occupance and legislation as response to change in the mother country, to international pressures and to internal forces.

From a synoptic view Hance's map of source areas of export production in Africa is most valuable in emphasizing the discrete 'islands' of production which are characteristic of the continent. In its location of 95 per cent of total exports by value, the symbols each representing 0·01 per cent, the geographer has at his disposal a quantified synopsis of major agricultural patterns operating within or in association with the money economy (Hance *et al.*, 1961). The pattern of these agricultural producing areas – ignoring in this context the mineral realm – emerges as one of *coastal* and *peripheral* islands, of *highland* islands, of *irrigation* islands and *special* islands. The year chosen – 1957 – was a high-water mark of colonialism in Africa and seems in retrospect singularly appropriate for the purposes of this study. Exports in that year showed 64·9 per cent of the total value deriving from vegetable products, of which the principal categories were stimulants and spices (28 per cent), vegetable oils (16·6 per cent) and fibres (10·2 per cent). Conforming with these production islands, one might also stress the importance of land alienated and settled by Europeans in High Africa

who make use of the labour pools of the intervening tribal land. These areas have their counterparts in Low Africa where land was set aside for agricultural concessions or has from an early date seen rapid increase in small-scale African production of certain traditional plantation crops.

The agricultural patterns associated with the large farms and plantations are in general related to certain obvious morphological features such as the arrangement of the crop, processing plants, roads and labour compounds but their effects are much more extensive than the immediate farm-complex. They usually generate high labour demands and create a *rural exodus* of employable males, enforced or voluntary. Degradation of tribal lands as a result of degenerating indigenous agricultural systems is as much a hazard at a distance of hundreds of miles as in the immediate vicinity. Because of belated intervention by administrations, conservation ordinances, resettlement and colonization schemes were often instituted long after perceptive agriculturalists had warned of incipient rural slums and gullied tribal lands. An additional factor in determining the major patterns of agricultural activity has been the growth of other enclaves of non-traditional employment where urban areas, due to administrative, industrial, transport and other functions, have expanded and accelerated the modification of traditional agriculture by creating markets, however small. Often the eccentric position of capital or primate cities has created in effect core areas with distinct pioneer fringes beyond which the agricultural patterns have experienced little direct incentive to alter; the existence of so-called 'Cinderella' provinces as in the case of the North Western Province in Zambia and the Ouadaï Province in Chad support this generalization. Yet there has often been a modification of this core area phenomenon in the line of rail or main road effect whereby native settlement and cash cropping have been attracted to a linear zone parallel to the routeway with resultant increase in land 'values'. This is evident in the examples of the Bas Congo–Katanga Railway where a remarkable diffusion of the Baluba of Kasai and associated intensification and increase in total area of land under cultivation has occurred; as Nicolaï states: 'le rail a simplement mis en contact la civilisation européenne et la civilisation indigène' (Nicolaï and Jacques, 1954). This extension of European attitudes to land via communications networks may be plausible in the case of the Dakar–Niger or Livingstone–Ndola lines of rail, but as O'Connor has significantly demonstrated for Uganda it may no longer be true that railways can promote economic development if a flexible road transport system operates (O'Connor, 1965).

Perhaps the most significant contrasts between African and European attitudes to the land may be summed up in the statement that natural

resources are effectively cultural appraisals. By whatever means the process of acculturation was directly or indirectly prosecuted, it was inevitably disruptive because the colonialists had too little time to appreciate their ignorance of the African milieu or African society.

Policies and patterns: aspects of action and reaction in the African Colonies

The Portuguese territories

Since 1951 when Portugal converted her colonies to overseas provinces, that country has further strengthened its determination to seek its own solution in Africa. Post-war conditions, which fortified more liberal policies in France or Britain and led to the more direct development of the African sector in various economies, have not ameliorated the lot of the non-assimilated in overseas Portugal. Although in combined areas Angola and Moçambique occupy 779,082 square miles and dwarf the 13,948 square miles of Portuguese Guinea, each has been overshadowed by the economic demands of Brazil. Although there are now probably 400,000 whites in Portuguese Africa, it has proved impossible to establish a large white-settler community in the face of the New World's greater attraction and for this reason the emergence of a distinct policy was but little earlier than those of other European powers arriving centuries later.

Portuguese policy operates on the basis of certain fundamental principles, of which the concept of political – and hence social and economic – unity between Portugal and her overseas provinces is particularly significant. This is expressed in strongly centralized administrative control, either at the territorial or Luso–African level and a domestic political situation not altogether typical of other European ex-colonial powers. Two juridical classes are recognized – the citizen and the native – and this explicit hierarchy underpins the philosophy behind the social and economic development by simplifying the issues involved in the contact between the institutions of the Western and of the 'primitive' culture. Recent concentration on African and *petit-blanc* peasant farming schemes would suggest that the view that the majority are simply instruments of policy having the right to develop toards *evolué* status may be changing.

Whereas Brazil was not neglected after its discovery in 1500, the interior of Moçambique was not effectively administered until after the military campaigns of 1895–9, Angola until 1907–14 and Portuguese Guinea until 1916. Until that stage feudal conditions characteristic of an earlier Europe had been preserved by the granting of land title in the form of *prazos* (estates) in Moçambique from the sixteenth century with the aim of stimulating European colonization in southern Africa. Exploited by their owners for slaves and tribute, these *prazos* degenerated into petty empires

which were able to defy Lisbon despite their being outlawed in 1832. It was not until the attention of other European powers was drawn to southern Africa that Portugal was forced to reform the system in 1890. Estates were sold to the highest bidder who in turn paid the government a proportion of tax revenue and undertook to cultivate and develop the land and to protect resident Africans. With this onset of modern development profitable operation became essential and by 1900 over two-thirds of Moçambique had passed under the control of the chartered concessionary companies. Chief of these were the *Companhia de Moçambique* which received its charter in 1891 and continued to exploit and administer the land westward from Beira between Zambezi and Save until 1942, and the *Companhia do Niassa* which was granted a charter in 1894 and sought to exploit 96,500 square miles between the Rovuma, the Rio Lùrio and Lake Nyasa on a thirty-five-year concession; the *Companhia do Zambézia*, granted a concession but no charter in 1892, commanded an area of about 60,000 square miles in the lower Zambesi area (Quelimane and Tete districts) until the title expired in 1929. This last company, unencumbered by administrative costs and benefiting from the enterprise of its sub-concession holders such as the Sena Sugar Estates Company, was more successful than the other concessionaires in developing areas vastly greater than metropolitan Portugal. Writing of the Moçambique and Zambézia companies in particular, Duffy has noted that during their short existence they 'had greater significance for the colony than had the *prazo* in three centuries. To a large extent they initiated the transformation of the interior of the province from a wilderness to an economically productive region . . . The benefits the Africans derived from their presence seem less than negligible' (Duffy, 1961).

The interest of the Portuguese territories lies in no small way in their remarkable failure to develop as settler colonies for a dominantly agricultural and overpopulated mother country. In the case of Moçambique, 44 per cent of which lies below 330 ft (100 m) and only 13 per cent above 3,300 ft (1,005 m), not only has white settlement proved to be disappointingly slight but also dependence on indigenous labour has proved acute and has brought the dual sectors of the economy into conflict through the operation of labour laws which in the past excited condemnation. Portuguese insistence that the African had an obligation to labour led to excesses in their native policy exemplified in Angolan recruitment for the São Tomé cocoa plantations and the Moçambique recruitment for the Witwatersrand. Changes in native labour policy were stimulated by foreign opinion and today labour is generally operated within the voluntary or contract category rather than the obligatory class, but the harmful effects of rural depopulation persist.

In Moçambique the indigenous agriculture is essentially of a subsistence character, the population (1960 Census – 6·6 millions) of such Bantu groups as the Maravi, Tonga and Shona, being relatively thinly settled away from the coastal areas and exploiting some 12·35 million acres principally under variants of shifting cultivation (Guichonnet, 1965). The internal division between native and non-native areas is not altogether clear since decrees setting aside reservations for the exclusive use of Africans have been fairly numerous since 1900. The 1955 *Native Statute* for both Angola and Moçambique stipulated that 'natives who live in tribal organizations are guaranteed, in conjunction, the use and development, in the traditional manner, of land necessary for their villages, their crops, and for the pasture of their cattle' (Duffy, 1961). In the absence of native courts, Portuguese civil and criminal law is operative and there is no recognition of individual rights in the native reserves. In Moçambique there were 2,501 separate European-type holdings in 1962, extending over 3·95 million acres, of which 988,400 acres were actually cultivated using a labour force of 134,416 Africans and a mere 1,302 Europeans (Guichonnet, 1965). Probably about 60 per cent of the agricultural exports originate from the European sector despite this great disparity in the cultivated areas and labour engaged – in Angola it is nearer 80 per cent – and a specialized pattern has emerged with plantations alone producing sugar, sisal and most of the tea. Certain crops, among which copra and maize are good examples, are grown by both Africans and Europeans and others solely by Africans. Of these cotton was forcibly introduced in 1932 and is extensively produced from what were originally compulsory African plots of about 5 acres per family operated under the aegis of the *Junta do Algodao*. Under this system the Africans received the seeds from concession holders who bought back the crop at guaranteed prices. Rice was similarly first introduced as an obligatory crop and, like cotton, culture led to serious ecological and social disequilibrium. As with native taxation, so obligatory crops were a feature of many colonies in a local endeavour to make them self-financing and thus to avoid a politically unpopular charge on the metropolitan budget.

In Angola the population is very thin in terms of total area, and the great Bantu groups such as Ovimbundu, Chokwe and others still practise extensive agriculture. Despite the much more common *planalto* areas climatically favourable to white settlement, Angola, which was effectively pacified much later than Moçambique, seemed primarily to serve as a labour pool. More than any other cultigen, coffee, first introduced to Angola from Brazil in 1837, dominates agricultural production and is of particular importance north of the Cuanza River; it is now the most important agricultural export commodity but this situation has brought about the implicit hazards of a monoculture as well as worsening the already great labour

shortages of plantation labour. Van Dongen has commented that 'labour demands on the part of the coffee growers have led each year to extensive displacement of African able-bodied men from their tribal villages, causing family hardship and depressing local birthrates' (van Dongen, 1961). Although the number of white farmers is only about 3,000, the Angolan economy derives a disproportionate benefit from their lands, between 70 and 80 per cent of agricultural exports stemming from this quarter. Coffee plantations, predominantly in northern Angola, required 85,647 African workers in 1956; sisal plantations another 29,000 (von Gersdorff, 1960). As in Moçambique, cotton was an obligatory crop after 1932, although it had been exported as early as 1856. So unpopular was it that it precipitated population drift to territories to the east and African families continue to cultivate holdings of about 2·5 acres under a similar concessionary arrangement to the detriment, particularly in Malanje District, of normal subsistence cropping.

The important and heavily capitalized plantation companies of the Portuguese territories stand in contrast to the settler policy of the *colonatos*, conceived nearly fifty years ago but not put into effect as modern enterprises until 1949. In Moçambique the Limpopo scheme of fourteen villages in which some 1,000 white and 500 black families had been settled by 1964 in an irrigated area of 37,100 acres is well known. In Angola the setting is distinct from the latter which lies at an altitude of about 330 ft (100 m), for it occurs at a height of between 3,200 ft (975 m) and 6,250 ft (1,905 m) in the *planalto* zone and extends through 38 *colonatos* in nine districts and involves about 2,900 farming families (Niemeier, 1966). The attempt to create a Lusitanian peasantry in her Commonwealth would appear to have reversed the *laissez-faire* policy of Portugal which in spite of *de jure* unification of black and white interests and opportunities has favoured the localized transformation of her territories into plantation landscapes, African cash cropping playing a hitherto minor role. The argument is often paraded that Portugal has, with the exit of the other European powers, passed out of the era of traditional colonialism and entered upon a new phase of mutual benefit to all Portuguese citizens, white and black; placed in a monopoly position vis-à-vis other European countries she can now, without her traditional antipathy towards foreign capital, press ahead with development of industry as well as agriculture orientated towards domestic markets (Neumann, 1965). If this be the case, Portuguese administrative policies may yet influence a more objectively implemented land-use pattern, benefiting from the mistaken initiatives lacking the historical perspective which has been so costly elsewhere in Africa and evolving the hybrid institutions which have eluded others in the search for acceptable development forms.

The Belgian Congo

That the Belgian Congo, a vast mosaic of landscape and ethnic components, should have passed into the control of a metropolitan country which had not even sought to be a colonial power yet inherited a colony of exploitation *par excellence* is not without its irony. In effect, by the state's reluctant annexation of the Congo Free State and the proclamation of the *Charte Coloniale* in October 1908, the Congo passed from nominal independence to colonial status. After 1885 and in accordance with the conditions imposed by the Act of Berlin, Leopold II's private 'estate' had in effect been an *international* colony. After 1908 the area passed through a second phase in which it was influenced by a unique combination of administrative, missionary and commercial forces, finding expression in the economic and social sectors to the ultimate detriment of political institutions. Concerning the decolonization process in the Congo, Young writes of this colonial trinity that 'each fashioned a formidable organizational structure in its own sector of activity' and that the ensuing colonial system was 'unparalleled in its penetration into the African societies upon which it was superimposed' (Young, 1965). The same author notes apropos of the administration that 'no Congolese, rural or urban, could have failed to perceive that he was being administered. In the urban centres this is hardly surprising, but what differentiated the Belgian system from others in Africa was the extent of its occupation and organization of the countryside'. Such an effective administration was achieved by a tight network of *secteurs*, composed of amalgamated native chiefdoms and given legal sanction as *circonscriptions indigènes* from 1933, within the purely administrative network of provinces, districts and territories.

The Free State had been characterized by a monopoly system in association with concessions which collectively extended over vast areas of 'vacant native lands: of three types, railway concessions covered 22·5 million acres, the Katanga concession 112·5 million acres and the forest concessions an immense undisclosed area' (Hailey, 1957). Under Belgium the system was regularized. Native land law recognized no individual land ownership, this being invested in the clan and allocated by the *chef de terre*, custodian of the land, as the need arose. The early administration recognized as tribal land only that which was in actual occupation, but this was modified in 1906 by a decree permitting a threefold increase on this inadequate allocation, and subsequent legislation, particularly that of 1934 and 1935, sought to protect native lands and rights of cultivation. The situation regarding the exact nature of such land under native occupation, however, remained ill-defined in the absence of specific tribal reserves following inconclusive attempts at delimitation. Thus those lands vested in the state could be disposed of on

a freehold or leasehold basis by the Government and this function was further delegated to certain concession-granting authorities. The broad effect of this change was a swing away from the crude exploitation of such forest commodities as wild rubber to a situation in which freehold was ceded to a concessionaire when specified conditions of development had been achieved.

Although the move towards the systematic individualization of native land tenure had begun as early as 1933, it was another twenty years before the first decree was issued. Two major phases of colonial policy can be discerned in this connection. In the initial phase the inflow of capital was encouraged by the grant of concessions, such as those of the Unilever associate *Huileries du Congo* (1911), which led to a great upsurge in palm product exports from rural areas. The formation of essentially urban-based private enterprises such as *Union Minière* in Katanga and *Forminière* in Kasai five years earlier had led to pressure on labour supplies and forced the entire country towards a state of imbalance between capital and labour. Subsequently there was a reversal of policy whereby the *classe paysanne* was fostered as a logical extension of the 'educational process' implicit in the obligatory cultivation programmes enforced since 1917. From a geographical standpoint the Congo can conveniently be considered as having suffered a progressive rural depopulation in tandem with a marked success in urban development; initially facilitated by labour recruitment, this largely male exodus subsequently received tribal sanction. After 1924 the administration's policy turned against excessive recruitment and set a ceiling of 5 per cent on the number of able-bodied Africans permitted to leave the village for long-distance migration, with provision for a total of not more than 25 per cent to be absent within specific work zones (Anstey, 1966). In fact the situation deteriorated rapidly in some areas with over half the able-bodied male corps being absent at any one time and this had predictable effects on the material and social fabric of the family, village and agricultural systems as well as side-effects on associated ecosystems. The Belgians went a stage further in emphasizing the dualism of Congolese society by providing areas in which those Africans who wished to live outside tribalism could exist in urban *milieux de liberté* and rural *centres extracoûtumiers*. So successful was this active detribalization process that between 1935 and independence this sector increased in numbers from 600,000 to 3 million.

The *paysannat indigène* policy, which had first been mooted in 1933, was not put into effect until the first resettlement schemes were set up in 1942. This official policy marks the second phase of major change in the Congo when serious and costly remedies against rural depopulation began to operate. By independence about 200,000, or 8 per cent of the rural population, had voluntarily joined these schemes and the Belgians began to

register solid achievement not only in raising living standards but also in controlling traditional shifting agriculture. None the less Europeans continued to play an important role in agriculture until Independence in 1960. In 1958 there were 113,000 whites in the Congo, of whom 9,621 were engaged as colonists. Although the amount of land ceded to private persons or companies by 1958 was only of the order of 11·6 million acres, or slightly more than 2 per cent of the total Congo, the million acres actually under cultivation represented 40 per cent of the total area under cash crops (INFORCONGO, 1960). With over 300,000 Africans in wage employment on farms and plantations, the marketed production of European holdings demonstrates the overriding areal importance of palm products, coffee and rubber, and confirms the prominence of this type of organization at the close of the colonial rule.

In some ways the late emphasis on African rural development parallels experience in the Portuguese territories, both administrations having decided to attempt to recreate in Africa the European peasantry. In an admirable study of the Congolese Kwilu, over one million of whom occupied one of the most densely populated areas of the territory, Nicolaï's conclusions are of great interest (Nicolaï, 1963). He wrote that 'L'administration n'a donc introduit aucune reforme importante, aucune culture nouvelle. Sa seule intervention effective consista en cultures d'ordre éducatif, c'est à dire en cultures imposées . . . L'administration n'a guère réagi (ou mal ou trop tard) contre l'exode rural.' The consequences of a policy expressed in what Anstey terms 'a whole series of achievements, principally material and most related to unreflecting economic purpose', are etched into the Congolese landscape but in fairness to the Belgian administration must be set against the scale of the territory and the practical difficulties of controlling the whole rather than sectors of the economy and society.

French territories

France, with over 4 million square miles of territory at the zenith of her colonial power, presents features of marked distinctiveness in her colonial policy, not least those which derive from Napoleonic centralization in the nation state, her atomized domestic politics, or her own loss of independence in 1940. Brunschwig has assessed the course of French colonialism up to 1914 demonstrating the effect of defeat in Europe in 1870 and France's search for renewal in colonial expansion (Brunschwig, 1966). Comparisons between Britain and France in Africa are particularly valuable since French domestic policy failed to stimulate the emigration characteristic of the British situation. Slower industrialization distinguished her from a Britain more concerned with calculated commercial gain than prestige and permitted her generals to carve out what were effectively military rather than

settler colonies. The over-all impression of the French colonial period is one of remarkable success achieved in integrating the African intelligentsia with metropolitan French culture, thereby emphasizing the contrasting patterns of acculturation between anglophone and francophone Africa. The French colonial policy aimed, to some degree idealistically, at assimilation with the mother country and although local differences in the colonies and trust territories existed, the central legislature and the Colonial Ministry in Paris, despite distinctions between metropolitan and colonial law, imparted a marked unity in the colonial empire, contrasting with the British Empire, each of whose territories were viewed as separate entities.

European settlement of the French African territories was in many instances hampered by their very vastness combined with relatively small population, difficult terrain and unpromising resources. Moreover, the closeness of such North African territories as Algeria and Tunisia to France understandably made them of greater practical interest. Algeria, in particular, acted as an experimental theatre where the conflict between French *colon* and native land-holder was played out and legislative and administrative machinery was developed to resolve it. Apart from those in North Africa, the French territories in Africa consisted of two great blocks, French West Africa (A.O.F.) and French Equatorial Africa (A.E.F.) based on Dakar and Brazzaville respectively, together with Togo and Cameroon in the West and Côtes des Somalis in the East. Malagasy (Madagascar) and the Comores may be regarded as distinct from this French tropical Africa. Even at the pre-Independence census of 1956, the number of French and other foreign citizens in A.O.F. did not exceed 90,000, of whom more than half were in Senegal, and A.E.F. totalled only 25,000, two-fifths of whom were in Moyen-Congo; Togo had about 1,300 whites, Cameroon about 17,000 and Djibouti less than 5,000. Judged by the criteria of effective settlement in tropical Africa, France would appear to have met with conspicuously little success in some areas, although the peculiar demographic shadow effect of the North African settlement goes far to explain this and the alternative stress on concessionary régimes and native agriculture. Another significant feature of the French tropical African territories involved their land-locked positions, isolating them in terms of exports and making their economic development heavily dependent on improved communications, particularly railways. This interior position of much of French Africa in the Saharan and Sahelian zones meant that as a culture area it was predominantly Muslim, and consequently much of the local law and custom was influenced by Muslim principles. Not only was the majority of population on many of the now autonomous states Muslim – Guinea, Senegal, Mali, Niger and Chad being examples – but, more significantly, the élites were Muslim. As in the case of the British in Nigeria, so

the French encountered and reacted to clearly differentiated social environments straddling the natural life zones; the pagan forest peoples were more subject to Christian missionaries and education and the Muslim savanna peoples retained institutions which were not necessarily amenable to changes implicit in an alien cash economy or modern techniques, for all their long-standing trans-Saharan trade links.

Founded in 1895, A.O.F. was administered from Dakar and Senegal became the core area for an expanding hinterland, Upper Volta being amalgamated as late as 1919 and Mauritania in 1920. The port of Dakar provided an outlet for railways converging on it from Mauritania and Mali, and the rail network relates strikingly to present areas of groundnut production both inside Senegal and in western Mali. Similar features are evident in the case of railways leading inland from the coast at Conakry, Abidjan and Cotonou. Indeed, it has been noted that 'the economy of West Africa has been completely reversed by the railway links between the Islamic states of the Niger basin and the old trading ports of the Gulf of Guinea . . . the new groupings in French-speaking Africa form themselves on the railways' (Carrington, 1960). The economic development of A.O.F. has been a slow process, Lord Hailey's *Survey* commenting that 'there was little pressure to secure land for colonists. An attempt to start a plantation system in Senegal in the nineteenth century had proved abortive, and henceforward economic policy was directed mainly to the development of the peasant economy' (Hailey, 1957). French land policy in the four territories of Moyen-Congo, Oubangui-Chari, Gabon and Chad, which had been federated in 1910 to form A.E.F., manifested a concessionary character which took as its model Leopold's Congo but avoided direct intervention by the state. After the granting of exclusive rights over agriculture, forestry and industry to various companies by the Commission of Colonial Concessions from 1899, more and more of equatorial Africa was ceded in return for cash payments and performance of certain administrative functions. Normally African reserves totalling one-tenth of the ceded areas were allocated, but in effect practically the whole of A.E.F. passed into the hands of concession-holders, and such was the frantic exploitation that French liberal opinion obliged the Government, when excesses were made public, to intervene. By 1910 the apogee had been passed and financial mismanagement sent the concession system into decline. Land which had been taken out of native hands when originally alienated was not, however, reallocated to the tribes but reverted to the state in terms of metropolitan decrees of 1899 covering *terres vacantes et sans maître*.

Progressively, exports changed from the uncultivated types such as rubber and timber to a widening range of cultivated crops such as cotton, coffee and cocoa, to which were later added groundnuts, tobacco, sisal and

other plants. At one extreme in Gabon, much of which was shrouded in rain forest including *okoumé*, export production has remained markedly localized as in the case of oil-palm, cocoa and rice, and the *paysannat* schemes seem to be in their infancy. At the other extreme Chad, a country of remarkably different physical conditions, strikingly illustrates the effect of introducing a new crop. Under the cotton monopoly *Cotonfron*, cotton production was commenced in 1928 and by the time of Independence extended to about 600,000 acres of largely peasant holdings and accounted for 80 per cent of exports by value. For the traditional cultural landscape such schemes were revolutionary in the long term, leading as they did with implementation of the *paysannat indigène* policy from 1952, to wholesale regrouping of villages. The history of cotton in A.E.F. has been a somewhat chequered one since its inception in 1924, despite the million and a half people in Chad and Ubangui estimated to be wholly or partially dependent on the crop. Thompson and Adloff state unequivocally that 'for nearly three decades the African farmer in northern A.E.F., was more a victim than a beneficiary of the official pressure to grow ever larger quantities of cotton' (Thompson and Adloff, 1960).

French administration was aided by a hierarchy of land, village and canton chiefs which facilitated operation of their policy which initially resorted to the *prestation* system of taxation whereby liability could be absolved by prescribed labour terms in lieu of cash payment. In the early years the concessionary companies perpetrated many abuses and even when labour legislation improved the situation the shortage of manpower on the plantations continued and necessitated contract labour by migrants from distant parts of both federations. Inevitably there were deleterious effects on native agriculture. Throughout French tropical Africa most land continued, in the absence of settler competition, to remain under traditional systems of ownership and in consequence when changes came they concentrated on converting *de facto* ownership to *de jure* forms, with individualization dependent on registration (*immatriculation*) of title. But by introducing French laws of possession and in particular the *jus utendi et abutendi*, which Dumont has criticized, the originally sound intention of developing a peasantry of proprietors rather than occupiers brought with it the seeds of future conflict between individual and national interests.

Seen as a whole, French tropical African territories demonstrate, nevertheless, a continuity of agricultural emphasis. De Carbon has calculated that four major commodities (groundnuts, coffee, cocoa and timber) accounted for three-quarters of exports in 1958 and 1938 (de Carbon, 1964). In many important respects the French territories under consideration suffered from a deficiency of capital investment up to the outbreak of

the Second World War, as did the Portuguese possessions, when compared with the British territories, although investment in *per caput* terms qualifies regional advantages; Frankel's estimates of total overseas investment in Africa up to 1936 suggested that the British Empire territories received £941 million (of which £523 million were invested in South Africa), the Belgian Congo £143 million, the Portuguese territories £67 million, A.O.F. £30 million and A.E.F. £21 million (Frankel, 1938). Certainly the attitude of the metropolitan power to foreign capital investment facilitated or hindered certain developments; France discriminated by compelling a majority French holding in any investing company whereas Belgium had an 'open door' policy, and as early as 1928 France had begun to consolidate her trading empire by a customs union and tariff system.

Post-war change in French African policy found its expression in the 1946 constitution which recognized that progress towards the original goal of either political assimilation with metropolitan France (i.e. overseas departments) or development of the status of associated state within the French Union might not be speedily achieved, and accordingly a transitional status of associated territory was envisaged, necessitating extension of French citizenship to hitherto juridically dualist colonial populations, albeit retaining a split franchise (Robinson, 1955). Development in the interests of local populations was accelerated by the formation of an investment fund, commonly known as *FIDES*, which drew on French governmental subventions committed to expenditure on agriculture, research and social infrastructure. In the case of A.E.F. the French credits had to concentrate particularly on an infrastructure which was, to quote Thompson, 'strengthened beyond its productive capacity' (Thompson and Adloff, 1960). In the case of A.O.F. high-cost new or continuing development schemes, such as the massive irrigation colonies of the *Office du Niger* and elsewhere, have transformed the agricultural patterns but, with the exception of the Ivory Coast and Guinea, the concessions never attained great size or importance and have not inflicted damage which has first had to be made good. Consequently the Africans in A.O.F. would appear to have taken greater advantage of the opportunities of participating in the cash economy, where natural conditions permitted this, than in most other parts of Africa.

Former German territories

It would be wrong to ignore totally the effects of German colonization, even though it was a mere episode, extending effectively only from 1884 until 1914, which gave way to the B Mandates of Tanganyika, Ruanda-Urundi, Togoland and the Cameroons, together with the C Mandate of South West Africa. With Bismarck's annexation of Lüderitz Bay in 1884, the contributions to African exploration of Barth, Schweinfurth, Nachtigal and von Wissman gained tangible advantages for Germany and led to a colonial empire of 700,000 square miles in Africa. Settlement was confined almost wholly to East Africa where the German East Africa Company, founded in 1891, operated for the entire period. Plantation agriculture was established in Kamerun (chiefly coffee) and Togo (cotton). The East African settlement concentrated on the Dar-es-Salaam and Usambara Mountains regions and white settlers numbered little more than 5,000. A breakdown of population indicates that there were only 685 planters and farmers in East Africa in 1911, 111 in Kamerun and 5 in Togoland (Henderson, 1962). Nevertheless the 80-year-old German-founded commercial plantations of west Cameroon retain their importance to the present day and Bederman has noted that 'except in the realm of human relations, the Germans were undoubtedly the most progressive of colonial rulers. Many of their problems were solved by scientific methods' (Bederman, 1966). Since many Germans privately repurchased their former plantations and farms or moved into the Portuguese territories, their effect on agricultural patterns in certain areas has not been entirely negligible.

The British territories

If France was characterized by centralization and a rational approach to her colonies, then Britain might be stereotyped as decentralizing authority by the indirect rule through existing political institutions and preferring the empirical to the theoretical approach. Certainly this simplification would serve to explain the great variations both between and within the former British territories. This variability is further complicated by geographical heterogeneity as such which differentiates territories on a basis of their suitability or not for white settlement. Their population was in some cases already dense and their institutions well developed; in other cases there existed a positive incentive to create settler colonies where climatic conditions so disposed and the consequent influx not only of Europeans but also Asian settlers served to sharpen land conflicts.

Early penetration of the ultimately British areas had been accomplished by traders and missionaries who were assisted in pacification rather than administration by the British Government. Early administration was a charge on various of the great chartered companies which followed in the footsteps of the private Sierra Leone Company of 1800, and the aloofness of the ruling caste vis-à-vis commerce tended to place administrators in the position of adjudicators between native and European interests. The British African Empire grew essentially from the amalgamation of territories hitherto administered by the Foreign Office, but the evolution towards a unified Colonial Office policy is a complex matter best left to historians.

Private enterprise laid the foundation of British spheres of influence and of these the Royal Niger Company (1886), the Imperial British East Africa Company (1888) and the British South Africa Company (1889) were particularly significant in this regard. The contrast between possessions in High and Low Africa is marked and the question of alienation of land is crucial, especially where the companies handed over administration to Whitehall and the concessions granted to them by local chiefs became matters of legal dispute. Large tracts of land were alienated for white colonization in both eastern and southern Africa and native reserves were set aside as early as 1894 in Southern Rhodesia and 1904 in Kenya. The obviously impending clash of interests in High Africa – in Low Africa concessions generally concerned specific mineral, forestry or other rights – was partially resolved by a Privy Council decision in 1918 on the Matabele Concession in Southern Rhodesia, which determined that unalienated company lands passed to the Crown. This decision implied forfeiture and to some extent enabled the Crown to redress the balance upset by wholesale confiscation of tribal lands. Pacification had led not only to spatial restriction of tribes but also to an increase in their numbers in areas of locally inferior soils and the new ruling facilitated extension of native reserves and creation of *native trust lands* – that is, areas administered for the benefit of the native inhabitants. The consequence of this complex division of certain territories into blocks of land alienated for white settlement, unalienated Crown Land, native reserves, native trust lands, native purchase areas, game and forest reserves and various other categories, have obviously been far-reaching in legal, social, economic and other terms. In the case of South Africa, where 89 per cent of the land was alienated to Europeans, and Southern Rhodesia, where the figure was about 49 per cent, the concept of native reserves has come nearest to the Roman practice of absolute separation of native and colonist and is effectively a segregation (*apartheid*). Elsewhere the marked dualism of society was nowhere so harshly discriminatory as in this region of Romano-Dutch law and could neither in scale of land holdings nor size of immigrant population, whether in Kenya or Zambia, support more than temporary white nationalism.

Private enterprise in Low Africa took on a different form and British West Africa was spared massive expropriation of lands. Cultural segregation was shared in some measure with settler colonies but for reasons of institutional conservatism. Lugard's 'invention' of *indirect rule* whereby the power of the existing authorities was consolidated, was born of necessity and realized by the gradual adoption of local government through the native authority. The dominant factor in this tribal organization, as Carrington suggests, 'was always land tenure and the West African policy intended that land should not be alienated. There were too many parts of the world . . . where recognition of tribal authority had merely enabled chiefs to sell the land to concession-hunters. Under the Lugard system the alienation of land was prevented' (Carrington, 1961). Peasant agriculture rather than plantation agriculture was the means by which traditional 'plantation' crops were produced on the encouragement of the Colonial Office and Udo has argued that this anti-plantation policy was, despite the sound intention to protect indigenous tribal life, a retarding influence in the case of southern Nigeria's economic growth (Udo, 1965).

In the case of Nigeria, its division into a colony and protectorate and the existence of some 300 tribes extending from the coast to the northern emirates has led to considerable diversity of land tenure and variations in agricultural patterns consequent upon cash cropping and steady population increase. Meek has investigated the complexities of land tenure and land administration in Nigeria and it would be wholly futile to attempt here any generalizations from this formidable survey save to note the gradual shift towards individualization of holdings both in Muslim and pagan areas and the creation of a free peasantry (Meek, 1957). Of great importance has been the role of native authorities since 1945 in disposal and control of land, and sales or pledging of land have increased to a point where fragmentation, sub-tenancies and other features, which may lead to the emergence of a landless proletariat, must cause concern. Nevertheless land utilization data collated by Meek show only 30,723 square miles under farm crops, and 3,935 square miles under tree crops, while 220,402 square miles from a total area of 339,169 square miles in Nigeria remain actually uncultivated bush or waste. The incipient pressures consequent upon increasing commercial value of land may therefore tend to encourage coalescence of the present nodes of agricultural cash cropping centred on the southern cocoa–palm zone and the cotton–groundnuts zone north from Kaduna.

British colonial policy, like that of other colonial powers, has undergone significant changes which have found expression in the visible landscape. From a *laissez-faire* economic policy, indirect rule spread with the strength of dogma throughout British tropical Africa and it only received a severe jolting when democratization of indigenous institutions began to be effected and the fragility of tribal institutions in the face of agricultural or any other change became manifest. Policies of the paramountcy of native interests – from 1930 – and the preparation for colonial self-government began to stimulate development in economic and social spheres as well as the political, and it became obvious that in place of annual budgeting, co-ordinated development plans were essential. The basis for accelerated development was laid by the Colonial Development and Welfare Act of 1940 and the series of colonial development plans which were formulated after 1945. The British Overseas Food Corporation and the Colonial Development

Corporation inaugurated numerous projects, both pilot and major in scope; some of these achieved success while others, despite large-scale, often mechanized operation, did not. As in other colonial areas, Britain appears to have swung increasingly towards creation of a 'middle class' African peasant, modelled in part on the success of his fellows on *paysannat* communal farms in the French territories. *Group farming* schemes involving relatively low capital investment achieved success in Nigeria and the *peasant farming* schemes introduced into Northern Rhodesia in 1948 were symptomatic of changed emphasis. Significantly there seems to have been ready transfer of successful concepts within the British sphere as well as a willingness to learn from Belgian and French experience. Given time this trend might well have led to a *convergence* of cultural landscape types both within the British sphere and, making due allowance for variance in ecological conditions, within colonial Africa as a whole. Dispersion of settlements and progressive enclosure in advance of *de jure* ownership became increasingly common.

In Uganda the British Commissioner, Sir H. Johnston, had already in 1892 begun to 'encourage the more intelligent among the natives to exchange their present communal holding which checks individual enterprise for the acquisition of personal titles'; in the Gambia the Governor introduced a form of native leasehold in 'waste lands' in 1895, and a comparable development occurred in the Gold Coast two years later with the publication of the Public Lands Bill (Branney, 1959).

This movement towards personal ownership, of either a freehold or leasehold character, has, however, remained slow throughout most of the colonial period, retarded by uncertainty of purpose in economic and social policy and the apparent antipathy of many African societies towards any promotion of individual interests at the expense of the group. In tropical Africa as a whole it remains the interesting exception to the rule although its accelerated application in the post-war years promised radical changes on the territorial rather than the local scale.

Conclusion

For any comparison to be made between former colonies or groups of colonies, the most appropriate method of analysis of agricultural patterns as expressions of administrative policy would seem to be not the sectoral approach, but rather the genetic classification of distinct types of *agrarian landscape* and the assessment of their areal and socio-economic importance. In examining this *Landschaftswandel* it would seem appropriate to consider particularly the three-dimensional aspects of any distributional patterns, since the *inversion* of the cultivated areas of which Pierre Gouru has written, whereby intensive techniques are, as in the Asiatic tropics, applied to the

lowest soils instead of clinging to the plateau surfaces or hill slopes, has often been initiated by the European plantation or government agriculturalist or more prosaically 'in the interests of good administration'. Similarly, the search for 'temperate' conditions has caused the European to extend greatly the altitudinal range formerly available to African agriculture. Stress has been laid upon dualism in society and economy and very largely this has been shown to hang on attitudes to land as a resource where rights *in rem* and rights *in personam* have seemed incapable of resolution. The selection of criteria for categories of agricultural patterns can lead to confusion if account is taken of such factors as bioclimatic regions, population–land factors and institutional features, with a resultant multiplicity of classes which clouds perception. Most agricultural patterns in tropical Africa would, however, seem to fall into one of a number of major categories if zones of overlap are disregarded, and the following provisional classification is suggested. Some explanation and exemplification of this landscape classification is called for, but it must be stressed that the categories are tentatively formulated in the interests of reducing the self-evidently multifarious landscapes of reality to simpler proportions. The suggested groupings derive from experience and evaluation in depth of a single colony made possible by former active involvement in provincial administration. Shorter visits to other African territories, together with selective reading of the literature, suggest that the classification may deserve a wider application.

1. *Archaic:* A group comprising unmodified shifting, semi-permanent or permanent traditional systems under customary tenure.

2. *Transitional:* A group showing features of regression or progression. The *degenerate* forms, developing as a consequence of over-population, male depopulation or related causes and displaying such features as erosion, excessive fragmentation and neglect; the *regenerate* forms display adaptation by adoption of new techniques and cultigens voluntarily, by direct but limited European intervention through soil conservation measures, well-digging, seed-farms, etc., or by such direct actions or agencies as road construction and private commercial operations.

3. *Ephemeral:* A special group including illegal squatters, displaced political refugees and other short-lived occupancies such as those associated with tsetse-fly or game clearance schemes, dam construction, etc., where agriculture nevertheless persists.

4. *Colonial:* This group comprises patterns arising from essentially *exogenetic* or *endogenetic* causes.

The *plantation* landscape is essentially a European introduction dependent on large-scale alienation or concession of land. The *large-farm* landscape, unlike the plantation, is usually confined to areas reserved for

white settlement. Both tend to develop labourseds far beyond their immediate environs.

African *settlement scheme* landscapes may be differentiated into irrigated and rainfall agriculture types and represent policies aimed at intensifying cash-crop production, diversifying existing patterns or widening employment opportunities. Some show evidence of developing from an existing base and are conventionally of the *peasant farm* type, with or without individual freehold or leasehold tenure. Others have developed from uneconomic disposition of holdings and merely represent reorganization by consolidation and the rationalization of communal land use. Others are on a scale often dependent on mechanization and strongly centralized control, co-operative marketing, etc., and approximate to the state farm or syndicate with share cropping or leasehold tenures.

Although in the strict sense no tribe in an African colony could entirely escape the notice of a European administration, and all were therefore subject to exogenous factors of change, in practice many were so remote from core areas and so beset by adverse environmental or locational factors as to continue virtually unchanged in their forms of agriculture. It cannot be over-emphasized how lightly administered were certain areas, particularly in the larger but more thinly populated territories, and it has been in such areas that survivals – in the shape of fossilized land-use patterns – are most significant. Policies of social and economic development were universally modified by the exigencies of two world wars and the retrenchments of the depression years and any detailed study of official reports covering single districts reveals how much of the colonial *pax* was in fact an enforced stagnation with mere interludes of activity. Since farmers are by reputation conservative, the term *Archaic* does not seem misplaced in describing the antiquated systems which exist where static factors outweigh the dynamic and an absence of land hunger is typical, although such stagnant situations may, nevertheless, quickly pass into the *Transitional* phase. Characteristically the areas covered by such archaic agrarian landscapes will be almost entirely self-sufficient in economic terms and denied access to commercial markets because of remoteness, inadequate communications or discriminatory marketing levies and tariffs; administrative and agricultural priorities at central government level would tend to the preservation of the *status quo*. The Kaonde, a group of shifting cultivators of the Congo–Zambezi watershed, were such an example. Their isolation was verified by the author when working as an administrator in a district of over 16,000 square miles (the size of Switzerland) yet populated by a mere 32,000 people, for most of whom the annual tour by the district officer was the sole contact with the white man's administration. As early as 1938, some 33 per cent of taxable

males were absent on labour migration, and by 1961 this figure had increased to about 60 per cent; yet this remote participation in the money economy had been compensated for by internal changes in the division of labour, rather than easily visible signs of progress or decline in the agrarian landscape as such, because the physical resources have had to support only low population densities. Another tribal case in which a traditional and archaic pattern has been retained would appear to be in the Jie area of Karamoja in north-eastern Uganda. The British ended large-scale movements of the essentially transhumant Jie, and the effect has been to differentiate the fixed homesteads (*ngireria*) at which older men and the women maintain the dairy herds and carry on agriculture, from the peregrinating stock camps (Gulliver, 1955). Writing of the Fur people in the Sudan, Lebon has noted how these sedentary cultivators, whose terraced slopes are remarkable, preserve 'an economy almost entirely self-sufficient owing to the inaccessibility of most parts of the Mountain (Jebel Marra) from the markets' (Lebon, 1965). While survivals of this sort are without doubt decreasing in number and extent, it seems probable that most larger territories embrace examples.

Throughout most parts of Africa the *Transitional* form is dominant among agricultural patterns since traditional systems have only been capable of maintaining food supplies without deterioration of the land where demand has remained under control. Pressure on land clearly arises from a steep rise in population, the introduction of cash crops (in addition to subsistence crops), the conversion from hoe to plough, and, in certain cases, direct competition with immigrant groups. Kraal manure is frequently unavailable for overworked soil and fallow periods decline as decreased yields set in. Where no increase in the farm area is available, over-cultivation and fragmentation of existing holdings usually appear and the resulting 'cultivation steppe' will be commonly exposed to excessive runoff, desiccation and ultimate degradation to bad lands topography. Alternatively, the breakdown of traditional agricultural systems may result from excessive wage migrations where able-bodied males are no longer available for such tasks as heavy bush clearance. Often this transition has led to degeneration in traditional systems which may be characterized by neglect of subsidiary crops and a consequent fall in the quality of the local diet. Degeneration has been a relatively common feature in many African territories and has commonly needed drastic governmental remedies, often involving the wholesale transfer of population or rehabilitation of landscape and thus involving the substitution of a *Transitional* landscape by one within the *colonial* category. The case of the Ngoni tribe, spatially restricted by the arrival of the British and the subsequent alienation of land to white settlers in eastern Zambia, is an example of an accelerating decline (Hellen,

1962). Similar land hunger arose in the Kikuyu areas of Kenya as well as in the Usambara and Uluguru Mountains of Tanzania, while in West Africa there are many degenerating areas adjacent to towns or cash-cropping land. The plain of Barotseland which Livingstone has described as bearing a close resemblance to the Nile Valley and whose people he described as never being 'in want of grain, by taking advantage of the moisture of the inundation they can raise two crops a year', has experienced a decline (Livingstone, 1857). This followed the ending of slavery (1906) and tribute labour (1926) which had made possible the construction and maintenance of a 400-mile network of drainage and navigation canals under the paramount chiefs and the cultivation of extensive peat seepage soils. Since that time the productive area has declined and difficulties have arisen over a high water-table re- stablished by this neglect; Barotseland has ceased to be self-sufficient in foodstuffs in a situation where land is still plentiful (Hellen, 1963). In certain highland areas the neglect of terracing or box-ridging has had a similar effect and parts of the Matengo area of south Tanzania demonstrated this deviation from good conservation practice (Stenhouse, 1944, quoted in Allan, 1965).

Transitional but regenerate forms are commonplace and may coexist alongside examples of glaring degeneration. One tribe may respond to change by conscious adaptation and another may languish in an identical habitat. Central government agencies may inject limited financial, material and technical aid with a similarly sporadic outcome. Unlike certain forms of colonial landscape pattern, the transitional but regenerate form does not represent a wholesale reorganization of agrarian landscape or society but rather a selective, albeit scientific, intervention of modest proportions. Mandatory rules have often had a greater effect than self-help, and soil conservation legislation has been particularly important in halting degradation of African areas. Prohibition of steep-hill-slope cultivation and the widespread adoption of contour ploughing, bench terracing and afforestation of interfluves, has proved beneficial. One of the classic areas is exemplified by the Kabale area of Kigezi in Uganda where steep slopes of red loam were supporting population densities in excess of one person per acre by 1943. The Babika were said to cultivate slopes up to 35° and to graze slopes of up to 45° and their numbers were further increasing through immigration and a high birth rate (Purseglove, 1946). Subsequent conservation measures following survey and controlled resettlement have supported the inherently good conservationalist practices of the people and the unwitting decline occasioned by congestion has been halted. In a less striking manner the compulsory introduction of certain crops has had a widespread regenerative effect, as has voluntary acceptance of crop rotation to overcome shortage of land.

Ephemeral patterns are, as implied by the term, short-lived occupances due to extraordinary events or short-term expedients. Areas were set aside in the immediate pre-war period for the resettlement of landless Kikuyu labourers from European farms and the Mau Mau emergency of the 1950s saw the so-called 'villagization' for security reasons of an otherwise typically dispersed Kikuyu settlement habit. Similarly, ephemeral patterns exist where, for example, refugee groups have moved into neighbouring countries (e.g. the movements from the Congo, Rwanda and the Sudan) or where squatters occupy overspill zones from which they can expect eventual expulsion. Illegal squatting appears to have been a recurrent problem both in European farming and plantation areas and persists into the independence phase. Illegal compounds and villages with their associated subsistence agriculture taking the form of peri-urban fringe-belt areas are a common feature of expanding towns and by their very nature must be regarded as ephemeral by the authorities. During major projects such as tsetse-fly clearance it has often been found necessary to concentrate a generally thin and scattered population into settlement corridors until rehabilitation has been completed.

Colonial landscapes are probably the most clear-cut of categories because of the scale or intensity of intervention of the imperial power. The plantation or large-farm landscapes are clearly distinguishable by the nature and scale of their organization and, notably, by concentration on a few generally exotic crop types which dominate vast areas. In general such landscapes represent an extreme expression of exogenetic forces made possible by an almost total disregard of the indigenous social environment. Settlement scheme landscapes represent, by contrast, a local balance between major European policy involving such aims as the development of export commodity production and the rational distribution of population or reorganization of land tenure within the limits imposed by the expectations and capabilities of the native groups involved. Scant attention has been paid to indigenous society in certain cases such as the major irrigation projects, even to the extent of importing alien African colonists; in other cases the pattern may represent a highly effective modernization of existing husbandry effected with the full co-operation of those people involved. In nearly all cases the settlement schemes and peasant farms have been well chronicled by colonial governments and their histories, if not their true costs, recorded in countless ministerial reports. Such zones or foci are, together with the areas retained as plantations and large farms, the key to further transition and transformation of the cultural landscape. The stage of active competition in land use and land ownership must inevitably place archaic and transitional categories under increasing pressure to change. In effect, with certain modifications, the *colonial* group of agrarian landscape

patterns becomes the post-independence *political* landscape, in so far as this latter type is an expression of state policy, which admits the inadequacy of traditional agriculture, and has the power to effect change.

Under whatever form of land tenure, however, many of the African territories are faced with the urgent necessity of providing non-agricultural occupations lest they be overwhelmed by population increase and frustrated by the inefficient political expedient of handing over land to the landless. The nature of the nationalist political platform of pre-independence days was such as to invest the slogan 'people without land deserve land without people' with the weight of dogma. If in retrospect much of the colonial legacy seems inappropriate to present African realities and the evolution of land policy, to borrow Dumont's description, 'anarchique', many of the forms imposed or experimented with by Europeans remain guide-lines in an area of limited choice. With a fresh start in Africa the administrations concerned have a unique opportunity to study the relative merits of external models – whether they be smallholder co-operative, state syndicate or commune – and to decide whether land reforms and hence landscape change should be imposed autocratically or democratically. In retrospect, decreasing returns may well prove to be the Achilles' heel of peasant agriculture, and hence the absence of an inherited prior commitment to peasant proprietorship in many countries will permit the introduction of systems offering the greatest productivity from land and people in a global situation where food deficits rather than economic growth demand immediate attention.

References

ALLAN, W. 1949. *Studies in African Land Usage in Northern Rhodesia*, Rhodes-Livingstone Pap. 19.

1960. Changing patterns of African land use. *Jl R. Soc. Arts* 58, 612–29.

1965. *The African Husbandman*, Edinburgh.

ANSTEY, R. 1966. *King Leopold's Congo*, London.

BEDERMAN, S. H. 1966. Plantation agriculture in Victoria Division, West Cameroon. An historical introduction. *Geography* 51, 4, 349–60.

BIEBUYCK, D. (ed.). 1963. *African Agrarian Systems*, London.

BOHANNAN, P. 1963. 'Land', 'tenure' and land-tenure. In BIEBUYCK, D. op. cit., 101–15.

BRANNEY, L. 1959. Towards the systematic individualization of African land tenure. *Jl afr. Admin.* 11, 4, 208–14.

BRUNSCHWIG, H. 1966. *French Colonialism 1871–1914*, London.

CARBON, L. B. DE. 1964. Problems of economic development of French-language countries and territories. In ROBINSON, E. A. G. (ed.), *Economic Development for Africa South of the Sahara*, London, 138–83.

CARRINGTON, C. E. 1960. Frontiers in Africa. *Int. Affairs* 36, 4, 424–39.

1961. *The Liquidation of the British Empire*, Reid Lectures of Acadia University 1959, London.

CHISHOLM, M. 1962. *Rural Settlement and Land Use: an Essay in Location*, London.

COLSTON. 1950. *Principles and Methods of Colonial Administration*, (Colston Papers), London.

DONGEN, E. VAN, 1961. Coffee trade, coffee regions and coffee ports in Angola. *Econ. Geogr.* 37, 4, 320–46.

DUFFY, J. 1961. *Portuguese Africa*, London.

DUMONT, R. 1961. *Afrique noire: développement agricole. Réconversion de l'économie agricole: Guinée, Côte d'Ivoire, Mali*, Paris.

1962. *L'Afrique noire est mal partie*, Paris; English trans. 1966, *False Start in Africa*, London.

FRANKEL, S. H. 1938. *Capital Investment in Africa*, London.

GERSDORFF, R. VON, 1960. Angola. *Die Länder Afrikas*, Deutsche Afrika-Gesellschaft, Bonn, 14.

GLUCKMAN, M. 1945. African land tenure. *Rhodes–Livingstone J.* 3, 1–12.

GOUROU, P. 1956. The quality of land use of tropical cultivators. In THOMAS, W. L. (ed.), *Man's Role in Changing the Face of the Earth*, Chicago, 336–49.

GUICHONNET, P. 1965. Le Mozambique: esquisse géographique. *Globe*, Geneva 105, 35–96.

GULLIVER, P. H. 1955. *The Family Herds. A Study of two Pastoral Tribes in East Africa. The Jie and Turkana*, London.

HAILEY, LORD, 1957. *An African Survey*, London.

HANCE, W. A., KOTSCHAR, V. and PETERC, R. J. 1961. Source areas of export production in tropical Africa. *Geogrl Rev.* 51, 4, 487–99.

HELLEN, J. A. 1962. Some aspects of land use and overpopulation in the Ngoni reserves of Northern Rhodesia. *Erdkunde* 16, 3, 191–205.

1963. Barotseland. *Geogr. Rdsch.* 15, 4, 149–60.

HENDERSON, W. O. 1962. *Studies in German Colonial History*, London.

HODDER, B. W. 1965. Some comments on the origins of traditional markets in Africa south of the Sahara. *Trans. Inst. Br. Geogr.* 36, 7, 97–105.

INFORCONGO, 1959–60. *Belgian Congo*, 2 vols, Brussels.

LEBON, J. H. G. 1965. *Land Use in Sudan*, World Land Use Survey, Monograph No. 4, Bude, Cornwall.

LIVINGSTONE, D. 1857. *Missionary Travels in South Africa*, London.

MAUNIER, R. 1949. *The Sociology of Colonies. An Introduction to the Study of Race Contact*, 2 vols, London.

MEEK, C. K. 1946. *Land Law and Custom in the Colonies*, Oxford.

1957. Land tenure and land administration in Nigeria and the Cameroons. *Colonial Research Series* 22, London.

NEUMANN, H. 1965. Portugal's policy in Africa. The four years since the beginning of the uprising in Angola. *Int. Affairs* 41, 4, 663–75.

NIEMEIER, G. 1966. Die moderne Bauernkolonisation in Angola und Moçambique. *Geogr. Rdsch.* 18, 10, 367–76.

NICOLAI, H. 1963. *Le Kwilu, étude géographique d'une région congolaise*, Brussels.

NICOLAI, H. and JACQUES, J. 1954. *La Transformation des paysages congolais par le chemin de fer. L'exemple du B.C.K.*, Institut Royal Colonial Belge, Brussels.

NYE, P. H. and GREENLAND, D. J. 1960. The soil under shifting cultivation. Commonwealth Agricultural Bureaux, *Technical Communication* 51.

O'CONNOR, A. M. 1965. New railway construction and the pattern of economic development in East Africa. *Trans. Inst. Br. Geogr.* 36, 21–30.

PURSEGLOVE, J. W. 1946. Land use in the over-populated areas of Kabale, Kigezi District, Uganda. *E. Afr. agric. J.* 12, 3–10.

RICHARDS, A. I. 1939. *Land, Labour and Diet in Northern Rhodesia*, London.

ROBINSON, K. 1955. French Africa and the French Union. In HAINES, C. G. (ed.), *Africa Today*, Baltimore, 311–36.

SCHLIPPE, P. DE, 1956. *Shifting Agriculture in Africa: the Zande System of Agriculture*, London.

STENHOUSE, A. S. 1944. Agriculture in the Matengo Highlands. *E. Afr. agric. J.* 10

THOMPSON, V. and ADLOFF, R. 1960. *The Emerging States of French Equatorial Africa*, Standford.

TROLL, C. 1950. Die geographische Landschaft und ihre Erforschung. *Studium Generale* 4/5, 163–181 (reprinted in 'Okologische Landschaftsforschung und vergleichende Hochgebirgsforschung'. *Erdk. Wissen*, vol. 11, Wiesbaden 1966).

1962. Die geographische Strukturanalyse in ihrer Bedeutung für die Entwicklungshilfe. *Basler Beitr. Geogr. Ethnol.*, Geographische Reihe 5, 25–52.

UDO. R. K. 1965. Sixty years of plantation agriculture in Nigeria: 1902–62. *Econ. Geogr.* 41, 356–68.

UNO. 1959. *United Nations Economic Survey of Africa*, New York.

YOUNG, C. 1965. *Politics in the Congo. Decolonization and Independence*, Princeton.

Hailey, Lord (GCSI, GCIE). 1945. An African survey.
London: Oxford University Press.

CHAPTER XVI

SOIL EROSION[1]

I. TYPES AND EFFECTS OF EROSION

It is only in the last few years that soil erosion has become recognized as one of the major problems facing the governments and peoples of most African territories, and as a problem which is growing yearly more acute. This is not to say that erosion is in itself a new factor. On the contrary, it has been going on since the world began; it is the process by which soils are formed from the parent rock, and by which the topography of the earth is moulded. The problem which Africa has to face arises from the acceleration of the normal rate of erosion by reason of the activities of man. It is in this sense of accelerated erosion that the term 'soil erosion' will be used in this chapter.

Erosion, in this sense, may be defined as mechanical changes in the soil, brought about by the agencies of wind and water. These changes follow upon and themselves accelerate the destruction of the vegetal covering normally protecting the earth's surface, and this destruction of vegetation, be it forest or grass, is the essential cause of accelerated erosion. The natural tendency of the earth is to cover itself with a protective shield of vegetation, whose composition is determined by conditions of soil, rainfall, and climate. For every part of the earth's surface there is a final stage of equilibrium between the vegetation and its environment, known to ecologists as the climax, which will be reached by the vegetation, provided that it is left free to develop. The intervention of man frequently upsets this delicate balance, and reverses the order of plant succession. African rain-forests, for instance—a climax type of vegetation—rarely recover from cutting or burning, but are usually replaced by park-like forest of a lower ecological type, sometimes called savannah. This savannah forest, in turn, may be reduced by frequent burning to a sparsely bush-clothed veld. Finally, overstocking and the continual grazing and trampling by cattle may so weaken the grasses that they succumb to drought, and the veld is then transformed into desert practically devoid of vegetal cover.

[1] This chapter was largely drafted by Mrs. Elspeth Huxley.

It is at this stage that erosion through the agencies of wind and water becomes acute. Vegetation normally protects the soil from the impact of falling rain, facilitates the percolation of rain water into the subsoil levels, takes up surplus moisture in its foliage, reduces the rate of evaporation, and shields the surface of the soil from wind. Its removal bares the earth to the direct impact of rain and wind, and to the drying action of the sun. These three elements may then in a very short space of time strip the mature topsoil wholesale from the earth's surface and remove it as silt in rivers or as wind-borne dust. This leaves exposed the sterile subsoil, sand or rock, incapable of supporting those types of plant life which can be utilized by man or his animals. In extreme cases the process may go so far that it becomes, like certain chemical reactions, irreversible: that is to say, nothing that man can do will restore the fertility of the land. This destruction of soil fertility, the most spectacular result of erosion, is the end product. The earlier stages are far more widespread and constitute the more serious problem; for in these earlier stages erosion can still be checked.

There are, broadly speaking, three types of erosion: sheet, gully, and wind. The first is the most widespread and dangerous, for it can proceed to a considerable length before any change becomes apparent to the eye. The primary cause is the cultivation of land on slopes without the use of terraces or other preventive measures. This form of erosion occurs to a greater or lesser extent on all slopes when the soil is left exposed and heavy storms are experienced; the tendency to it is increased where shallow ploughing has resulted in a hard pan a little below the surface; its severity varies with the type of soil and with the steepness of the slope. The first effect, which usually goes unnoticed, is the removal of the finer soil particles in suspension, leaving the coarser particles behind. These finer elements in the physical structure of the soil fill an important function in helping to bind soil particles into crumbs, upon whose size the quality of the tilth and the capacity of the soil to retain moisture and soluble plant food largely depend. Their removal leads to a deterioration in the capacity of the earth to support plant life. The coarser residual soil, moreover, leaches readily, and stores of humus rapidly become exhausted.

In more extreme cases the topsoil may be stripped bodily from the slopes and carried into the rivers by heavy storms. It is computed that many areas in the highlands of Nyasaland are losing soil at the rate of a quarter of an inch a year.[1] In Kenya an instance of the loss of 12 inches of topsoil in a year has been noted, and in one case an inch of soil was removed from a maize field in a single storm.[2] While sheet erosion is generally associated with cultivated land on hill-sides, it may also affect badly denuded grazing land in undulating plains; for example in Karamoja, in the Eastern Province of Uganda, observers have commented upon 'a vast sheet of muddy water rapidly moving over the surface of the country'.[3]

Gully erosion is more obvious, and frequently follows sheet erosion. When no vegetation is present to impede the flow of storm water, that proportion of rainfall not absorbed by the soil finds its way downhill in a series of rivulets whose channels are widened and deepened by every downpour. A vicious circle is set up. As the channel grows wider and deeper, the quantity and velocity of the water which pours down it after each storm grows also; and the power of the torrent to tear soil from the sides and bed of the gully is correspondingly increased. Gullies not infrequently start as small creases in the surface of a ploughed field and develop within a few years into chasms 20 or 30 feet deep. In the United States it is estimated that 13,143,000 acres have been destroyed by gullying.[4] Almost any channel or track is liable to develop into a gully; in Africa roads, railways, and paths made by stock going to water or to their kraals are particularly dangerous. In South Africa and Basutoland this form of erosion has become particularly severe. Loss of soil is increased by the cutting back not only of the main channels but of tributary gullies, known in South Africa as sluits, which then spread outwards from the heads of the gullies as small lateral channels.

Both sheet and gully erosion are brought about by the action of water. A third form is that resulting from the action of wind.

[1] A. J. W. Hornby, *Denudation and Soil Erosion in Nyasaland*, Nyasaland Department of Agriculture, Bulletin No. 11, 1934, p. 9.

[2] G. V. Jacks and R. O. Whyte, *Erosion and Soil Conservation*, Imperial Bureau of Soil Science, Technical Communication, No. 36, 1938, p. 95.

[3] E. J. Wayland and N. V. Brasnet, *Interim Report on Soil Erosion and Water Supplies in Uganda*, 1937, para. 90.

[4] *Report on National Planning*, National Resources Board, 1934, p. 171.

Open treeless plains, where no obstructions break the force of the wind, are particularly susceptible. In their natural state such plains are generally protected by grass cover, but when this grass is removed, either by cultivation or by over-grazing, wind erosion may strip the topsoil from the land. The most striking recent examples of this have occurred in the United States, where dust storms have robbed millions of acres of the great plains of their topsoil. In Africa dust storms have not yet developed on a large scale, but wind erosion is a factor of growing importance. The harmattan of West Africa carries with it sand particles from the Sahara and may be a factor in the spread of desert conditions in Northern Nigeria.[1] In north-western Kenya the recession of the waters of Lake Rudolph has left stretches of fine sand now being deposited over the land by the strong south-easterly wind which blows for a large part of the year.[2] So-called dust-devils, harmless enough when vegetation protects the earth, occur frequently in many parts of Africa, and, as cultivation extends, their significance as removers of topsoil cannot fail to increase.

The harmful effects of these three forms of soil erosion do not cease with the removal of the topsoil on which plants depend for their biochemical nourishment and physical support, and with a consequent decline in crop yields and in the carrying capacity of pastures. Erosion has several secondary results, of which the most important are: the silting up of dams and reservoirs; the escape of a large proportion of the rainfall as surface run-off before it can be utilized by plants; and a consequent fall in the level of the ground water-table, leading in turn to seasonal flooding and to the drying up of rivers.

Most of the topsoil that is moved downhill by sheet and gully erosion sooner or later reaches a river and is ultimately washed out to sea or into one of the great inland lakes. The Yellow River in China is said to transport 2,500,000,000 tons of soil every year.[3] South Africa is said to lose some 187,000,000 tons of silt annually to the ocean.[4] Rivers which have overflowed their banks regularly

[1] See below, p. 1103.

[2] A. M. Champion, 'Physiography of the Region to the West and South-west of Lake Rudolf', *Geographical Journal*, vol. lxxxix, no. 2, 1937, pp. 97–118.

[3] See G. V. Jacks and R. O. Whyte, op. cit., p. 58.

[4] *Final Report of the Drought Investigation Commission*, U.G. 49, 1923, p. 66.

for centuries, as, for instance, the Nile, or many of the great rivers of India, have deposited much of their load on the land, and built up rich alluvial soils; where, however, the load of silt is greatly increased by cultivation of hill-sides in the watershed, and where rivers are confined in their course owing to the depth of their valleys, the silt is carried out to sea. If, in its downward journey, it encounters reservoirs and dams, some of it is deposited, and the structure which was built to hold water rapidly fills with earth. This silting up of reservoirs has become a serious problem in the United States[1] and Australia,[2] and the same problem has already arisen in Africa. The loss of capital which follows the silting up of reservoirs is, of course, enormous; and more serious still is the consideration that, where reservoirs are built to store water for irrigation,[3] the future of the whole irrigation project may be endangered. In India it has long been recognized that the chief argument for the reservation of the forests in the Himalayas is the necessity for the conservation of the sources of the great Punjab rivers and of the Ganges.

Soil erosion reduces the proportion of the rain water which penetrates into the soil and becomes available either for the support of plant life or for the replenishment of springs and wells; it increases the proportion which escapes into the rivers as 'surface run-off'. In Africa, where rainfall is so often the limiting factor in agriculture or stock-raising, this aspect deserves special consideration. Effective rainfall is that part of the total precipitation which is absorbed by the soil; that which escapes either by evaporation or as run-off is wasted. The rate of evaporation is everywhere high in Africa, and if losses by surface run-off are added to losses by evaporation,[4] it will be seen that figures of total rainfall there are apt to be very misleading. As will subsequently be shown, the South African Drought Investigation Commission of 1923 did not believe that the annual rainfall was decreasing, but held that its effectiveness had decreased, since a larger proportion was being lost to the soil through increased surface run-off.[5]

Surface run-off increases where vegetal cover is reduced, since

[1] H. M. Eakin, *Soil Conservation Service Report*, 1935.
[2] Statement by State Rivers and Water Supply Commission in *Melbourne Age*, Sept. 22, 1937.
[3] See below, p. 1081.
[4] See Chap. I, p. 14.
[5] See below, p. 1080.

obstacles no longer impede the flow of water, and the soil is no longer kept open and porous by the roots of trees and plants. By far the most efficient type of vegetal cover is deep-rooted natural forest, where run-off is often negligible. Grass, while less efficient than forest, is still much less wasteful than the majority of annual crops, for the run-off may be considerable when the land is left bare and trampled after harvest. Unless preventive measures are taken, a higher rate of surface run-off normally accompanies an increase in cultivation, and there can be no doubt that in Africa a bigger proportion of the rainfall is reaching the sea unutilized than was the case a century ago. To this extent, therefore, the severity of the droughts from which Africa so often suffers has been increased by man.

Springs and wells are fed by reserves of water stored in the subsoil or rock underground. If these reserves dwindle, then wells dry up, springs are reduced to a trickle, and rivers that once flowed strongly all the year round fail altogether during dry periods and run only during and immediately after periods of rain. The more water lost as run-off, the less is available for underground storage: one of the most serious effects of increased surface run-off, therefore, is a fall in the level of the ground water-table. Such falls have been observed, and to some extent measured, in many parts of the United States;[1] in Africa the same phenomena of falling water-tables and dwindling rivers exist, although accurate measurements appear to be lacking. Examples of rivers which flowed all the year round twenty or thirty, or even ten years ago, and now consist of a chain of waterholes in dry weather and a muddy torrent in wet, have been quoted from almost all African territories. Apart from the Saharan examples,[2] the cause of which is a subject of some contention, there are many others. Dr. Robert Laws has listed twenty large streams that have ceased to flow in the Mombera District of Nyasaland since he first took up his residence there, nearly fifty years ago. The level of lakes in Uganda is steadily falling, especially Lakes George, Edward, and Kioga,[3]

[1] W. R. Chapline, 'Range Research in the United States', *Herbage Reviews*, vol. v, no. 1, 1937, pp. 1–13.
[2] E. P. Stebbing, 'The Threat of the Sahara', Extra Supplement, *Journal of the Royal African Society*, May 25, 1937, p. 7.
[3] V. E. Fuchs, *Report of Cambridge Scientific Expedition to the East African Lakes*, 1930–1.

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and in Kenya many once perennial streams have now become seasonal.[1]

A corollary to the dwindling of rivers and streams during dry seasons is the increase of flooding in wet seasons. Storm waters, no longer checked by forest and bush, flow down gullies and hill-sides into the river-beds; and streams, suddenly swollen, become converted from feeble trickles into rushing torrents heavily charged with silt. It is now an accepted thesis that such flooding is greatly augmented and in some cases caused by deforestation of the watershed. In France, for example, the correlation between floods and deforestation has been demonstrated in the Savoy region. Between 1738 and 1912, 21 per cent. of the forests of this region were destroyed; and whereas during the eighteenth century only eight floods occurred in the area affected, in the nineteenth century the number of floods rose to thirty-eight.[2] It is at the time of such flooding that irreparable damage is done by the removal of soil in the form of silt. Evidence from many parts of Africa points to the fact that within the last twenty or thirty years such sudden floods, which often subside as quickly as they arise, have become more numerous and more extreme.

The question of a falling water-table needs special consideration in view of the fact that in many parts of Africa action is being taken, by the sinking of new boreholes, and the deepening of existing wells, to extend the water supplies available to man and beast; and indeed it has been suggested that a part of the solution of the overstocking problem lies in opening up new areas for grazing by the provision of wells.[3] It is obvious that if the demands made on the underground water-store increase while available supplies continue to shrink and recede, wells provided by governments at considerable cost, with the idea that they will constitute permanent sources of supply, will afford only temporary relief, and will indeed create an even worse position. Catchment tanks and dams might be preferable to wells, as being cheaper and easier to construct and maintain.

Soil erosion leads to chemical changes in the soil too complex to

[1] H. L. Sikes, *The Underground Water Resources of Kenya Colony*, 1934, p. 10.

[2] A. Magnein, Communication read to the Upstream Engineering Conference, Washington, D.C., 1936, p. 228.

[3] Sir F. Stockdale, *Report on his Visit to East Africa*, C.A.C. 345, 1937, pp. 88 ff.

be dealt with here, but all tending in one direction: to reduce fertility of the soil and so to impair its efficiency as a supporter of plant life. This, in turn, can have only one result, the reduction of the capacity of the land to maintain human or animal life. This point needs special consideration in Africa, where other factors may be causing, in many areas, a rapid increase in both human and animal populations; in parts of the continent the demands of population are already throwing such a strain on the land that its productivity is actually declining. It has been noted, for example, that in Northern Nigeria, on the fringe of the Sahara, 'the whole population is actually increasing whilst the means of supporting it are obviously and visibly decreasing'.[1] The highlands of Nyasaland are stated 'now to be incapable of supporting one half of the population that they did one hundred years ago'.[2] The same story can be told of many other parts of Africa, from the Sahara to the Cape; and in all cases the stripping of vegetal cover from the land, either by cultivation or by grazing stock, is one of the causes.

II. CONTROL OF EROSION

Excessive soil erosion can, fortunately, be remedied. Since the destruction of vegetal cover is the prime cause, the restoration of such cover is the most obvious remedy. Reafforestation is now regarded as essential for the protection of soil and of head-waters on steep slopes, especially in watershed areas. Actual replanting is expensive, and few administrations can afford it; but results of great value can be obtained by a closure sufficient to allow of a process of natural growth, even if it be of a 'secondary' nature. Protection of existing forests, now practised to some extent in all African territories, is a recognition of the essential part which forests play in the stabilizing of soil fertility, water supplies, and climate. The proportion of Africa's land surface under forests is, however, dangerously low, being less than one-third of the extent considered by experts to be the ideal, which is usually taken to be 30 per cent. though some officers would accept 25 per cent.[3] On level or undulating land where protection from forests is not essential, it

[1] E. P. Stebbing, 'The Encroaching Sahara: the Threat to the West African Colonies', *Geographical Journal*, vol. lxxxv, no. 6, 1935, p. 609.

[2] A. J. W. Hornby, op. cit., p. 8.

[3] See Chap. XIV, p. 1000.

may still be necessary to provide a cover of grass if the soil is to be retained. But to restore the natural vegetal cover to all parts of the earth's surface threatened by erosion would mean the withdrawal from cultivation of large areas of agricultural land. This is obviously an impracticable course. The problem of the soil conservationist is therefore to devise means whereby agriculture and stock-raising can be carried on in regions susceptible to erosion without causing permanent damage to the soil. It is proposed here to review briefly those methods which have been devised and found to work satisfactorily.

(a) *On Cultivated Land*

The most ancient, universal, and effective method of increasing absorption and reducing run-off on cultivated land is the use of terraces. The origin of the terrace is lost in antiquity, but its use in Japan, China, the East Indian Archipelago, and the Mediterranean countries has enabled agriculture to be carried on, and large populations to be supported, in regions where erosion would undoubtedly have reduced the rich hill-sides to infertile rocky slopes within a few generations had no such measures been taken. Terracing is most highly developed in countries where rice is the staple crop.[1] In Africa, although rice is indigenous,[2] terracing (except where recently introduced by Europeans) is almost unknown, though the Chaga on Mount Kilimanjaro make use of it, and on Ukerewe Island, in Lake Victoria, an elementary form is practised. In recent years there have been developed methods by which the principle of terracing can be fitted into modern systems of farming at a very much lower cost than that of the traditional narrow-base structures, known as bench terraces, whose demands on labour are extremely exacting. The simplest of these methods is the construction of small earthworks, in the form of ridges or banks, which follow the contour of the slope and arrest the flow of water and the drift of soil. A somewhat more elaborate structure is the broad-base terrace, of which the Mangum terrace now widely used in America is a form. This requires the use of simple levels in addition to various specially adapted farm imple-

[1] J. Thorp, 'Soil Erosion in China', *Journal of Association of Chinese and American Engineers*, vol. xvii, no. 4, 1936, p. 183.

[2] See Chap. XIII, pp. 894–5.

ments for its construction; but, once built, it is a permanent and efficient structure. Cultivated land which is contour banked or broad-base terraced must thereafter be ploughed along the contour, which is in itself a minor preventive measure against erosion.

Apart from these and other variations of terracing, several simple anti-erosion measures have been devised. One such measure is the planting of narrow strips of a soil-binding crop (e.g. lucerne, clover, beans, Sudan grass, &c.) at intervals along the contour of the slope, the main crop being grown in between such bands of wash-resistant vegetation. This is known as strip-cropping. Another is the use of cover crops sown, as a rule, shortly before harvest in order to ensure that the land shall not be left without some protective vegetation after the main crop is removed. Other methods of avoiding erosion involve alterations in the basic system of farming designed to increase the humus content of the soil, and to reduce the period during which the land is left bare of vegetal cover.

It is now a commonplace of agricultural practice that the restoration to the soil, in the form of artificial fertilizers, of those elements taken from it by plants, is not enough to maintain fertility, however carefully the chemical loss may be made good. Without the addition of humus derived from organic matter, the land 'loses heart', the tilth deteriorates, and the soil's capacity to absorb and to retain moisture becomes seriously impaired. In this condition it falls an easy prey to erosion. An important factor in conservation, therefore, is to maintain the humus content of the soil. It is probably true to say that if there is one panacea which conservationists would like to see more generally applied than any other, it is the spread of mixed farming. This system ensures that a fair proportion of any given farm shall be kept under grass cover, and provides the means, in the form of manure, for maintaining the humus content and the physical condition of that part of the farm which is cultivated. If a grass ley is rotated with crops, moreover, the system ensures that every part of the farm in turn shall be rested, and its humus content restored.

Attempts are being made to introduce mixed farming in parts of Africa.[1] Where mixed farming is impracticable—as, for instance,

[1] See Chap. XIII, pp. 960–3.

in parts subject to severe animal diseases—humus content may be maintained by the addition to the soil of green manures or of compost. Green manuring with leguminous crops only proves effective in regions where rainfall is fairly well distributed; in regions of low and rigidly seasonal rainfall the ploughed-in crop does not break down satisfactorily. In these areas the break-down of organic matter—in this case crop residues, weeds, and waste material of all sorts—can best be effected not in the soil but outside it, in compost pits or heaps; the resulting humus, in a fine state of division and ready for use by the plant, is then applied to the soil. Adaptations of the method of humus manufacture in compost pits devised by Sir Albert Howard at Indore,[1] by which plant and other residues which would otherwise be wasted are put to good use in helping to maintain soil fertility, are being examined in several parts of Africa. In Kenya, for example, a District Officer has evolved a simplified system for the native farmer,[2] and the Agricultural Department has conducted a campaign in favour of a compost pit for every village.

(b) *On Pastoral Land*

Erosion on pastoral land is a result of the destruction of grasses by over-grazing, by trampling, and by veld fires. The remedy is to devise and apply a system of veld management which will adjust the numbers of live-stock to the capacity of the land to maintain them, and give the grasses a chance to re-seed themselves at suitable intervals. In working out such a system, the first step where possible is a survey to determine the carrying capacity of the land. This will vary greatly, not only in different years, but as between the dry and rainy seasons of each year. The next step may often be, therefore, to classify areas as dry- or wet-weather pastures, and to arrange for a rough system of rotational grazing between the two, which will give each area intervals of rest when the grasses can set and shed their seeds.[3] Pastoral tribes, in their natural state, had worked out some such rough system for themselves, but often it broke down with changes brought about by

[1] A. Howard, and Y. D. Wad, *The Waste Products of Agriculture*, 1931.
[2] A. D. Hall, *The Improvement of Native Agriculture*, 1931.
[3] See Chap. XIII, p. 971.

European rule; a well-known instance is that of the tribes in British Somaliland, where each tribe used at one time to have its own dry-season grazing ground, or *jilal*, which it guarded at the point of the spear.

The distribution of water has a vital bearing on the question of grazing control. Where rivers are few and far between and wells widely scattered, grazing is confined to belts on both sides of the rivers and to circles, centred on wells, whose radius cannot exceed the distance a beast is able to travel without water. In some regions, therefore, large areas of pasture in between these grazeable circles, and beyond the grazeable strips bordering the rivers, are useless for stock. In those regions the provision of new wells would release hitherto sterilized pastures for the use of stock.[1] Another factor which leads to the over-concentration of stock is the herding of cattle into kraals or *bomas* at night. The grass both within these enclosures, and on the tracks leading to them, is then totally destroyed, and the bare patches which result often act as foci of wind erosion. The substitution of a system of paddocking for that of kraaling is therefore one essential method of erosion control. Attention was first called to this question by the South African Drought Commission, which recommended a campaign to extend the use of fences, proof against jackals whose depredations are largely responsible for the custom which prevails in the Union of kraaling sheep.[2]

The control of fires is an essential part of veld management. Since time immemorial, pastoral natives have fired dry grazing in order to promote the growth of young green shoots; European graziers adopted the custom and often became its strongest supporters. Perpetual burning weakens or destroys the roots of grasses and plants, increases run-off, destroys organic matter in the soil, and hastens the progress of soil desiccation and erosion. It is particularly dangerous near the head-waters of streams, where devegetation leads to shrinkage of springs and to flooding after storms. The matter has been studied carefully in South Africa. The Drought Commission considered that 'the ultimate goal should be to stop all veld fires', but concluded that this was

[1] See Chap. XV, p. 1052.
[2] *Final Report*, op. cit., U.G. 49, 1923, p. 41, and see below, p. 1080.

impossible, and that steps should be taken to discourage them, and to encourage tree planting. Later studies[1] have suggested that total abolition may not always be desirable, since veld burning destroys ticks and in some areas (e.g. Natal) suppresses coarser grasses which mark the first stage in a plant progression towards scrub and towards forest.[2] This can only apply, however, to wetter regions, and to controlled burning. Experiments in the southern Cape Province suggest that if firing takes place before the grasses are dried out, the heat is less severe and destruction largely confined to the surface, not affecting roots or surface soil. The conclusion that uncontrolled veld burning is an unmixed evil is nowhere in dispute. The question of how to maintain control is, however, a difficult one, and a solution has not yet been found; there is, in the British colonies, an increasing tendency to utilize the rule-making powers of native authorities for this purpose, and if the measure is not always effective, it has at least an educative influence.

Other measures designed to strengthen the vegetal cover of the veld have been considered. One is the selection and breeding up of strains of grasses which will increase the carrying capacity of the veld. Considerable attention has been paid to this in South Africa, where Dr. Pole Evans has selected and bred a large number of drought-resistant and heavy-yielding strains,[3] and to a lesser extent in Kenya, where experiments in planting eroded areas with indigenous Kikuyu grass are being made. Allied to this method (whose chief disadvantage is its expense) is the introduction of exotic drought-resisting plants, such as Australian saltbush, to provide cover and food for stock. The planting of tree belts, the afforestation of hill-tops, the reconditioning of badly denuded areas by digging staggered trenches to arrest soil-wash on slopes, and the fencing and sealing of gullies by means of dams, are auxiliary methods of erosion control practised on pastoral land.

Finally, the complex question of the elimination of uneconomic stock cannot be divorced from that of veld management. If uneconomic stock is defined as animals maintained for purposes other than the supply of food and clothing or for sale, then a very large

[1] C. F. M. Swynnerton, *How Forestry may assist towards the Control of Tsetse Flies* (memo. presented at the 4th British Empire Forestry Conference), 1935.

[2] L. C. C. Liebenberg, 'Veld Burning', *Farming in South Africa*, vol. ix, nos. 99 and 100, 1934.

[3] See Chap. XIII, p. 972.

proportion of the cattle and goat population of Africa is uneconomic. The problem is a psychological one: so to change the attitude of the native towards his domestic animals that they become not tokens of wealth or a form of currency, but sources of income. This adjustment would admittedly involve a revolutionary change in a habit of great social and religious significance; but if it could be made, then natives might be taught to adopt such standard practices (at present often rejected) as the castration of inferior males, supplementary feeding, calf rearing, and, above all, the limitation of stock on any given pasture to a number which will not merely survive but will thrive on the available feed. Discussion on how best to persuade them to do so has been proceeding for many years. One main stumbling-block is that the bride-price is generally paid in cattle or goats among both pastoral and agricultural tribes. Efforts to encourage the payment of bride-price in cash have met with some response among educated Africans, but little among the bulk of the tribesmen. Various possibilities have been put forward, such as Sir Daniel Hall's suggestion of striking coins bearing the image of a goat or cow, or providing special tokens shaped like live-stock and redeemable in ordinary currency, to bridge the psychological gap between the use of animal and of mineral tokens of exchange.[1] No experiments, however, appear to have been conducted, and although the question is one of the most urgent of those arising from culture-contact,[2] anthropological studies have not yet indicated any method whereby substitution of cash for cattle and goats might be hastened.

Another method of approach is to encourage Africans to consume more meat, milk, and dairy produce, a procedure desirable not only on grounds of health, but because once a native has learnt to regard his stock as a source of food he is likely to attach importance to the quality of his cattle rather than to their quantity. Yet a third line of attack is to assist him to find an economic outlet for his stock,[3] either by establishing meat factories which buy his cattle for cash, or by teaching him better methods of preparing his hides and skins, or by instructing him in ghee manufacture and the setting up of small dairies. The chief obstacle in the way of these methods

[1] *Report of the Kenya Agricultural Commission*, 1929, p. 31. See also Chap. XIII, p. 973

[2] See Chap. II, p. 22.

[3] See Chap. XIII, pp. 937–40.

(which are being applied in varying degrees to several territories) is the conservatism of certain pastoral tribes, and their lack of any strong desire to obtain cash. Cattle owners do not, as a rule, evince the same enthusiasm as other types of African for clothes and other trappings of civilization, and they have not the same need for furniture and household goods. Cash to them is often of less use than cattle. There are also external factors which govern progress on these lines; meat factories,[1] for example, can only absorb a limited number of cattle, depending on the demand for meat products; and the price offered for goats cannot be made attractive, since the only part which is saleable in world markets is the skin.

All these three lines of approach to the central problem of livestock limitation—substitution of cash as bride-price, increased consumption, and increased sale—have been, and are being, followed. The difficulty is to make action effective before pasture denudation has gone too far to be reversed. In some quarters the opinion has been expressed that education alone will prove too slow a process. In some arid regions even three or four years of severe over-grazing, followed by soil denudation and perhaps wind erosion, may be sufficient to destroy a pasture. In Kenya, for instance, it has been suggested that parts of the Turkana, Suk, and possibly Wakamba and Mbere reserves have already been eroded by over-grazing to a point where pasture cannot be satisfactorily re-established.[2] It has therefore been suggested that government regulation of the numbers of stock allowed to graze over certain badly denuded pastures can no longer be avoided, and that compulsory culling of stock may have to be enforced if the land is to be saved. It is recognized that compulsory de-stocking would result in difficulties for the administration, and possible hardships for individual natives, but it is suggested that the alternative of permanently abandoning considerable areas of grazing land would in the long run involve greater difficulties and severer hardships. No pronouncement of general policy on this matter appears to have been made, and no compulsion has yet been applied in any purely native part of Africa[3] to enforce

[1] See below, pp. 1093, 1098. South-West Africa has a factory at Okahandja.
[2] *Report of the Kenya Land Commission*, Cmd. 4556, 1934, pp. 241–6.
[3] Compulsory de-stocking was introduced in the Ukamba reserve in 1938.

the reduction of existing flocks and herds; perhaps the only measure definitely aimed at this purpose is the special tax on surplus cattle imposed in Ruanda-Urundi. It may be said, however, that the adjustment of the numbers of stock to the capacity of the pasture to support them is the only ultimate method of controlling erosion on pastoral land. It is self-evident that an administration should, before taking any action, call in the aid of anthropological inquiry and advice.

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V. CONCLUSION

There are certain difficulties inherent in a study of soil erosion, whether in Africa or elsewhere. It has been made clear[1] that the term has here been used throughout in the sense of accelerated erosion, due to the action of man. But it is never easy to distin-

[1] See above, p. 1104.
[2] M. Marlatchy, quoted in G. V. Jacks and R. O. Whyte, op. cit., p. 66.
[3] See Chap. XIV, p. 1097.
[4] G. Tondeur, *L'Érosion du sol*, Propagande et Colonisation, no. 15, 1937.
[5] See above, p. 1056.

guish the damage due to the direct action of man from that which natural forces must inevitably occasion. The task is all the more difficult when the area under observation is, like the greater part of Africa, one of unstable climatic equilibrium. There is always the danger that the observer may be led to regard as due to man, and therefore capable of redress by him, matters for which there is, in the nature of things, no ready remedy. In the particular case of Africa a survey of the extent of erosion, consisting as it does of a summary of unrelated expert opinions, cannot be regarded as a scientifically objective statement. Erosion may appear, from the evidence, to be a serious problem in one territory and of little significance in another; but this impression may be largely a result of the greater interest taken in the subject in the one territory than in the other, which may in turn be traced to the personality of the officers principally concerned. Nor can the efficacy of the anti-erosion measures taken in different territories be fairly compared from the evidence available. Propaganda among natives, for example, is a method employed in many government campaigns, but its value depends upon the weapons used; it may be worthless; on the other hand, if energetically handled, it may be very effective. This summary can only be regarded, therefore, as a rough guide to the subject.

Even so, certain facts clearly emerge. The first is the widespread nature of the problem. Hardly a territory is free from the threat or the reality of erosion in one form or another. A second point which arises is the need for factual surveys of soil conditions, types of vegetation, extent of stocking, and the agricultural customs of the people, in order that a clear picture may be obtained of the extent to which soil deterioration has already proceeded, and of the factors making for its acceleration or the reverse. Only on the basis of such concrete information can a sound policy of soil conservation for any particular area concerned be evolved; for, while the principles are the same everywhere, the practice must vary widely according to soil, climate, the use to which the land is put, and the customs of the people who inhabit it.

The survey will vary in value for different territories, since the range of potential damage from erosion, and the form in which the damage may come, also differ widely. The problem has a very

different aspect on the Belgian Congo and in East Africa. But there can be no territory which can afford entirely to neglect it, for soil conservation is of universal interest in Africa. Except in the regions where minerals are of predominant importance, the wealth of the African people can be derived only from the soil; if the soil fails, then the ideals of African advancement must fail too.[1] A rising standard of living cannot be based upon a falling level of soil fertility. In most countries of Europe, where the maintenance of fertility is taken for granted, soil is generally regarded as a fixed and constant element in a changing world. This attitude is a dangerous one when applied to Africa, because the assumptions on which it is based are false. Tropical soil is not constant, it is changing always; easily destroyed, only time can recreate it; unwisely treated, it will cease to yield its harvests in a very few years.

The main conclusions which emerge from the material set out in this chapter would seem to be that in no territory where erosion has become severe do the measures being taken appear to be adequate to reverse the process; and that, in spite of much that has been done, no co-ordinated policy has yet been formulated for the British African dependencies. Though conditions vary from place to place and must be independently studied, the main lines of any conservation policy must be the same throughout tropical Africa. A falling water-table on one side of a boundary is a matter of concern to the neighbouring administration, as also are such erosive factors as blowing sand and flooding along river valleys. It is, therefore, a matter of urgency for the various governments in Africa to correlate their policies. There appear, however, to be considerable differences in the extent to which regulations regarding such matters as veld-burning or protection of forests and water supplies are at present applied. No territory has yet adopted a soil conservation ordinance dealing with the matter in a comprehensive way. Nor has the question of development in relation to conservation been sufficiently considered. It was the fashion half a century ago to regard the resources of Africa as 'unlimited'. Now it is realized that not only are they limited, but that the limits are

[1] See *Report of Commission on Higher Education in East Africa*, Colonial 142, 1937, pp. 14, 16.

lower than was at first supposed. Questions such as how far development can be pushed without overstraining the capacity of the land are beginning to arise, and it is clear that, if development is not to be wasteful or even harmful, they will require serious study. These matters also bear an interesting relation to the questions of land tenure discussed in the second part of Chapter XII; it will in particular be necessary to consider how far subdivision may safely be pushed before the point is reached where the land unit is too small to support a family without deterioration, having regard to the apparent need of African soils for periodic rest.

The central element in soil conservation is, as has been stated, the maintenance on the land of sufficient vegetal cover to prevent damage by wash and wind, and to safeguard water supplies. In Africa this resolves itself into four main problems: the preservation of existing forests and the afforestation of steep slopes and hilltops;[1] the control of overstocking and the application of scientific pasture management;[2] the protection of water supplies;[3] and the reorganization of native agriculture, so as to extend mixed farming where possible, and to protect cultivated land by terracing, cover crops, green-manuring, strip-cropping, and other means.

The main obstacles to the solution of these problems are two in number: lack of money and lack of African co-operation. The first is mainly a local problem, although help from the Colonial Development Fund has been forthcoming in several territories.[4] Each country has to classify the claims on its revenues according to its most fundamental needs, and, as was remarked of the question of water supply,[5] the claims of soil conservation are certainly not less than those of some of the social services which now engage a large share of public expenditure. The second is one of the most difficult problems in the complex question of soil conservation. There are certain aspects of soil erosion work in which the state can take direct action, as, for example, the reservation of forests, or the execution of large conservation works at the head of rivers. But if a remedy is to be found for widespread mischief such as the

[1] See Chap. XIV, pp. 984 ff.
[2] See Chap. XIV, p. 984.
[3] See Chap. XIII, p. 971.
[4] See below, p. 1113.
[5] See Chap. XV, p. 1052.

deterioration of soil or pasture, a vast mass of individuals must co-operate in the work, and their share in it will often involve them in much additional labour and the sacrifice of immediate profits. Governments will seek by various methods to obtain this co-operation. The French will look to the influence of their chiefs, who are now gradually taking the character of a body of trained native assistants.[1] Both France and Belgium will have at their disposal the methods of 'educative cultivation'.[2] The British administrations will use the services of the 'native administrations', and have, indeed, as has been shown, already begun to do so on a wide scale. But none of these agencies can in the long run be effective unless the conviction is widely spread in African society that soil conservation is for the benefit of the individual more than for that of the state.

Some observers have doubted whether the quality of propaganda now carried on by certain of the British territories is sufficiently well organized. At present such propaganda is one of many duties performed by Administrative Officers, by Agricultural Officers, and by native members of agricultural staffs; but it is made less effective by the small proportion of both Administrative and Departmental Officers who really know the local languages. In a few territories (e.g. Kenya and Tanganyika) the subject is being introduced into native schools. With the exception of the issue of posters in Swahili by the Kenya Arbor Society (an unofficial body), the showing of a soil erosion film in East Africa, and a projected experiment in vernacular broadcasting in Kenya,[3] and some slight use of the native press,[4] it has not been found possible to make much use of modern methods of propaganda. Further activity is clearly required, though it must be realized that at present only a limited use can be made, for this particular purpose, of the methods of propaganda used in civilized countries. The public which has to be reached is one of cultivators and pastoralists; to most of them the cinema and similar devices represent an alien and unfamiliar world, and the lessons conveyed by these means do not always strike them as relevant to their own circumstances. The task of persuasion will necessarily

[1] See Chap. IX, pp. 484 ff.
[2] See Chap. XI, pp. 630 ff.
[3] See Chap. XVIII, p. 1300.
[4] See, e.g., *Mutende*, no. 24, Feb. 1938, p. 10.

be a long one; but the most persuasive argument is, and will continue to be, an ocular proof of the benefits which the use of the new methods can ensure. That the lesson is not an easy one is shown by the difficulties encountered by the Union scientific departments in dealing with their European farmers; with the African native the difficulty is all the greater because measures considered necessary to conserve soil in some cases involve fundamental changes in his customs and outlook. The attitude of pastoral Africans to their stock, the need for the replacement of live-stock by money as the medium of exchange, and possibly alterations in native land tenure involving the introduction of individual tenure, are obvious examples. Some reference has already been made to the lack of attempts made to approach these problems from the anthropological or psychological point of view, although they are fundamentally problems of native social structure and psychology.[1]

Even with more extended propaganda, however, and with the anthropologist's help, one exceptionally difficult problem is likely to remain. It is doubtful whether pastoral natives could, in general, be persuaded to acquiesce in the voluntary reduction of their stock. The herdsman is, almost universally, more conservative and more tenacious of his point of view than the agriculturist, and the deeply ingrained habit of reckoning wealth in terms of stock is unlikely to yield quickly to propaganda or advice. Meanwhile the mischief done by overstocking is cumulative, and governments in certain areas must face the question whether stronger methods of persuasion should be used, and, if so, how they could be applied. Such possibilities as a progressive stock tax rising with the animal's age, and of erecting meat factories and compelling the sale of a proportion of herds over a certain size to the factory at a fixed price, have been considered, and each has its own difficulties. No government would embark on a policy of compulsory reduction of stock except with the gravest reluctance. On the other hand, the fact cannot be denied that in some areas the land cannot be prevented from complete degradation into desert unless the pressure of stock is relieved. A point apparently deserving special consideration is the rapid increase of goats. These animals are

[1] See above, p. 1069.

seldom used extensively either for food or for any economic purpose; and in some areas they have destroyed vegetation completely and caused the worst forms of erosion.

The protection of water supplies, vital to Africa's future, is now recognized to be bound up with the restoration of forest and grass cover to hill-sides and crests. Forest policy in the African dependencies is discussed in Chapter XIV. From the point of view of erosion, a more active policy of afforestation seems needed. A considerable lack of uniformity exists in the legislation framed to protect springs and streams. The enforcement of some general minimum standard of care by passing laws or regulations (where they do not as yet exist) on the lines already laid down in some territories, prohibiting cultivation or grazing within a certain distance of all streams, and controlling fires on watersheds, might prove practicable. Something has already been said elsewhere of the need for a more thorough investigation of the underground water resources of certain areas.[1] The building of small earth-dams to control the head-waters and upper reaches of rivers, on the lines developed in Basutoland and South Africa, is another method which holds possibilities for other territories. The question of how far the provisions which exist in many African territories for the calling out of native labour on works intended for the public benefit can be used in regard to soil conservation measures appears also to be worthy of consideration.

The needs of soil conservation, which have only been generally discussed in the last few years, have not yet been reconciled with policies which were in operation before conservation was regarded as a major problem, and were, therefore, framed without consideration of the dangers of soil erosion. Contradictions can be traced in the policies of various territories. On the one hand, there is the desire to increase production as quickly as possible in order to raise the standard of living of the people; on the other hand, is the fear that, if expansion of cultivation outstrips the spread of conservation measures, permanent loss of soil fertility and the ultimate impoverishment of the people will result. On the one hand, veterinary scientists control stock diseases with a resulting increase in the numbers of inferior cattle; on the other

[1] See Chap. XIV, p. 1026.

hand, District Officers find in many places that pastures are being destroyed wholesale. At one moment the introduction of ploughs may be urged, at another ploughs may be condemned as causing erosion; in one area the clearing of tsetse bush is regarded as an urgent health measure, in the next tsetse is regarded as the preserver of bush and hence of water supplies; in one region the cultivation of cotton is regarded as the key to progress and prosperity, in the next it is accused of destroying the fertility of the soil. These and other incipient contradictions can only be resolved by interdepartmental and interstate consultation, and by co-operative planning.

It is to be regretted that there is in Great Britain no one body which can deal specifically with the range of questions arising in connexion with the problem of soil conservation in Africa. There is, however, an increasing interest in the subject, to which the extensive journeys of the Secretary of State's technical advisers have repeatedly called attention.[1] The only fund at the disposal of the Colonial Office for this purpose, the Colonial Development Fund, has been used in growing measure to finance anti-erosion measures. Whereas in the first seven years of the fund's existence, up to March, 1936, only 10 per cent. of the moneys had been devoted to land reclamation, drainage, and water projects, in the year 1936–7, 36 per cent. of the money voted, amounting to £293,643, went for these purposes.[2] In the eleven months ending February, 1938, £234,120 went to land reclamation and water measures in Africa. The value of this assistance would be enhanced if an expert inquiry could now be initiated, which would deal with all the areas most seriously affected, and form the basis of the interdepartmental consultations, or the interstate discussions which, as suggested above, are required in order to formulate a co-ordinated scheme of action.

[1] See, for instance, Sir F. Stockdale's *Reports*, op. cit.
[2] Cmd. 5537, 1937, p. 28.

Sudan, Government of. 1944. The report of the Soil Conservation Committee, Sudan Government. Khartoum: McCorquodale and Co.

PART I.

Report of Soil Conservation Committee

CHAPTER 1. INTRODUCTION.

The Soil Conservation Committee was set up on December 13th, 1942 by the following letter of authority :—

"His Excellency the Governor-General has decided to appoint a Committee to be known as the Soil Conservation Committee, with the following composition and terms of reference :—

Composition.

Chairman : Dr. J. D. Tothill, C.M.G., D.Sc., Director of Agriculture and Forests.

Members : Lt.-Col. C. P. Fisher, M.R.C.V.S., Director Veterinary Service.
J. Smith, B.Sc. (For) Chief Conservator of Forests.
G. Andrew, M.Sc., Government Geologist.
G. M. Hancock, O.B.E., Sudan Political Service.
B. Kennedy-Cooke, M.C., Sudan Political Service.

Terms of Reference.

(a) To report on the present situation in the Sudan with regard to soil erosion and desiccation and the availability of rural water supplies for the human and animal population.

(b) To make recommendations in respect of any of the above matters and of any measures of legislation or taxation which may be required for the carrying out of such recommendations.

(c) To draw up a programme of work covering a stated period of years for the implementation of the recommendations.

(d) To provide estimates of the capital cost of carrying out the programme and of the future maintenance costs involved.

The Director of Agriculture and Forests will arrange for the secretarial work of the Committee to be undertaken in his office.

The Committee will report to His Excellency through the Financial Secretary."

A programme designed to circumscribe the nature of the enquiry to be conducted was drawn up and was agreed to as follows :—

A. Collection of Factual Data.

1. To arrange for a statement of facts re changes of climate and environment in glacial and historical times, due :—

(a) to change in basic climate.

(b) to the activities of man and his domestic animals : (discuss the general trend of occurrences, at *e.g.*, Erkowit and Tokar, dunes, grass fires, etc.)

2. To arrange for the preparation of density maps for human beings and for domestic animals.

3. By circular to Governor, to ask for maps of each Province showing distribution of wells and hafirs of all types.

To decide on a classification prior to circulation.

To ask for this data also to be summarised in tabular form.

4. To ask Governors for a reasoned statement of the additional wells of all types, hafirs and small reservoirs, provision for which should, in their opinion, be included in the first 5-year programme for development of rural supplies. This statement should include water supplies required for rural domestic use and for cattle, by the province and by all departments working in that province, excluding the Railways.

5. To obtain from the Finance Department a statement of the annual expenditure on rural water supplies for the five years ending with December 31st, 1942.

B. Subjects for Discussion.

1. Desert Creep. If the facts show a southward creep to review the steps that might be taken to arrest this creep such as (a) the control of animal grazing, particularly goats and camel, and (b) the planting-up of belts of forest in principal areas.

2. Tokar dune formation and the Tokar position generally.

3. The Red Sea Hills.

4. The Grassland—Acacia cycle in the Gedaref areas, with proposals for its planned management.

5. The Grassland—Acacia cycle in the main rain dura growing areas of the Blue Nile Province, with proposals for the orderly management of these important areas including fire control and provision of water supplies.

(a) on the clay plains.

(b) in the river valley above Sennar.

6. The Grassland—Acacia cycle in the Upper Nile Province, with proposals for its orderly management in the difficult areas concerned including the control of fires, the provision of water supplies, the better control of cattle, and where necessary, the moving of villages.

7. The agricultural lands of Kordofan Province, with proposals for the prevention of erosion by contour bunding, contour strip planting, afforestation, control of animal grazing etc.

8. The annual grass problems in Equatoria Province, with a view to deciding whether or not controlled early burning should be adopted. The Imatongs in particular to be reviewed in order to have the same policy for both the Uganda and the Sudan slopes.

9. The reafforestation of catchment areas, yielding water supplies for important groups of people in the Red Sea Hills, the Fung, Kordofan, Darfur and Equatoria; with a suggested five-year programme of work and an estimate of its cost.

10. Special reclamation projects such as the building of dams in Kordofan, with a list of such projects considered suitable for inclusion in the five-year plan.

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11. The existing forest policy of the Government in its relation to soil and water conservation.

12. The question of the perimeter protection of towns, with a suitable programme.

13. Rural communities and water supplies.

14. The general question of stock in the Sudan in relation to soil deterioration and erosion, with proposals for the orderly exploitation of the cattle industry in its relation to the soil conservation problem. The provision of cattle markets, the taxation of cattle and all related subjects.

15. The general question of taxation in its relation to soil conservation, with proposals designed to spread equitably, as between individual communities, provinces and the Central Government, the costs of the five-year programme recommended.

(*C*) To draw up a detailed five-year programme of soil conservation showing the total cost and the manner in which it is recommended that this cost should be spread between the Central Government, the provinces, and the communities concerned.

(*D*) To recommend an organisation regarded as suitable for carrying out the programme recommended.

This programme has now been carried out and the report embodies the conclusions come to in the course of the enquiry.

For the first three meetings the Committee had the advantage of the advice of Mr. Kennedy-Cooke whose long experience of Red Sea Hills conditions and whose botanical knowledge were of special value to the Committee and greatly appreciated.

Altogether 14 meetings have been held by the Committee. It had been intended to complete the work in January 1944 but a delay of four months occurred owing to the otherwise fortunate circumstance of two members of the Committee being permitted to proceed to the United Kingdom on long-overdue home leave.

CHAPTER III.

RECOMMENDATIONS.

It is not easy to arrange the subject matter of this part of our report in logical sequence and for convenience the projects recommended are first dealt with in some detail province by province.

A. Northern Province.

In this Province agriculture is almost entirely confined to lands of the Nile valley. The river is constantly heightening with silt the basin lands, cutting away silt islands and forming new ones, throwing out of use sagia lands by isolation from water through changes in the course of its channel, and bringing new sagia lands into cultivation by the same process. These are inevitable processes that do not lend themselves to human control and in any case the damage done in some areas is compensated by the creation of new lands elsewhere. Pump schemes on lands above the flood level are the surest way to create stable conditions in this area and except to secure pumping stations from bank erosion we do not recommend attempting to control these processes.

The large towns, however, all have perimeters passing into desert conditions owing to the grazing of camels and goats and to the illicit cutting of the acacia scrub for domestic fuel. We recommend that active steps be taken to control these deteriorating perimeters for the purposes of preventing dune formation, reducing the dust menace in the towns, and providing alternative grazing grounds for the poor man's milch animals. For the larger towns it is uneconomical to provide a local fuel supply, and supplies by rail from wetter latitudes must be accepted as the solution.

The Atbara town perimeter.

We recommend making a beginning with the control of the perimeter of the principal town of Atbara where the amelioration of conditions will directly benefit the important and hard-working Railway community.

The Director of Agriculture and Forests had already recommended the establishment of a modern dairy for the supply of clean milk, to be located on a small pump scheme to the north of the town between the river and the railway. In order to relate this project to the perimeter problem generally the Chairman asked the Governor to set up an ad hoc Committee to make comprehensive recommendations.

This Committee consisted of the Governor, Mr. Crawford, the Deputy General Manager Mr. R. H. Robertson, the Senior Medical Officer Dr. J. F. E. Bloss, the Acting Chief Conservator of Forests, Mr. W. L. Marjoribanks, and the Senior Inspector of Agriculture Mr. C. H. Richards.

The report of Mr. Crawford's Committee is attached as Appendix XIII and, with the exception of the proposal to macadamise the aerodrome runways, which should pend the development of air traffic, we accept the recommendations in full in so far as they relate to the control of the perimeter.

B. Kassala Province.

In this province there are a number of projects that require to be dealt with. These are the Tokar town perimeter, the control of dunes and gullies on the Tokar delta, the control of the Erkowit Rest Camp area, and the planned management of the Acacia-Grassland clay plain in the Gedaref area.

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The Tokar Town Perimeter.

Tokar town became partly buried a few years ago by an enormous dune of delta silt and part of the dune was removed by light railway. The Committee is satisfied that the dune was caused by deterioration of the perimeter by cultivation, by lack of vegetation, by grazing of domestic animals and by loosening of the soil surface by animals coming to drink at wells situated in the area. It is also satisfied that the method now being adopted, by the District Commissioner and Inspector of Agriculture, of controlling the perimeter by the sowing of adlib (*Suaeda*) whenever rains permit, by closing the perimeter to cultivation and to domestic animals, both for grazing and for drinking, is the right policy to pursue. As revenue arising from the delta is an appropriate source of funds no action other than full support in principle of the control measures now being adopted appears to be required by the Conservation Committee.

The Control of Gully Formation in the Delta.

A series of deep gullies occurs between the two main delta levels and has increased considerably in the last 20-year period. The importance of control is not very clear because redeposition is occurring on the lower delta which is thereby being improved.

Control by broad-based contour bunds at the gully heads is not practicable because any such bunds are rapidly breached by a stream of water. No action on these lines is recommended by the Committee.

Improvement of lands below the gullies.

The land below the gullies is generally somewhat poorer than that at higher levels and much of it is salty. It would be greatly improved by the addition of a few feet of new silt and as part of the waters of the Baraka river passes out to sea it appears that it might be worth while exploring the possibility of adding useful land to the delta by constructing with heavy machinery a broad-based bund behind the seashore in order to trap these waters and cause silt deposition. The clay fraction increases as one approaches the sea and it seems just possible that a broad-based bund at the 1 or 1.5 metre contour might withstand the impact of the remnant of the flood, particularly if spreader bunds were constructed to break up the force of flow. Should a broad-based bund prove effective it would be necessary to heighten it periodically *pari passu* with silt deposition. With a view to improving the quality of the lower delta and so off-setting the spoliation of lands due to gully formation the Committee recommends that the earth bank along the coast be repaired and heightened and be converted into a broadbased bund designed to check the flow of waters now escaping to the sea.

Control of dune formation on the delta.

In Appendix III is a note on some of the changes in the Baraka delta between the years 1921 and 1941 by Mr. R. C. Hardie, until recently Director of Surveys, who made the original survey of the delta in 1921 and who revisited the area in 1941. Mr. Hardie's conclusion is "that the condition of the delta to-day shows a tremendous deterioration over 1921," when, with a few exceptions, "the bulk of the triangle was clear of dunes."

The position now is that silt dunes are in active formation over a large part of the delta and from Mr. Hardie's note it is clear that the delta is a miniature dust bowl created by the intensification of agriculture that began in 1921.

Because great areas are now being thrown out of cultivation by the formation and creeping of dunes, the Committee recommends that active steps be taken to reclothe with adlib (*Suaeda*) the parts of the delta not under crop and to prevent

domestic animals from destroying this vegetation until it becomes established. Insufficient information is available as to what the complete vegetation should be and how it should be maintained. There are indigenous small trees, bushes and annuals that may also be useful and mesquite may have local possibilities. We recommend that while immediate and active steps be taken by the Agriculture and Forests Department to plant up as much as possible of the uncropped delta to *Suaeda*, at the same time a study should be made by the Economic Botanist and Chief Conservator of Forests or his nominee to ascertain the range of plants that can usefully be used for clothing the area in vegetation and how these several plants may best be established. We also recommend that these two specialists should study the use of plants or other obstacles to induce water spread, and devices for the removal by wind of silt deposit.

THE RED SEA HILLS.

(a) *Control of the Erkowit Rest Camp Area.*

As this project is being dealt with satisfactorily we wish only to say that we regard all the work being done as necessary for the preservation of the area. In our view the cause of the extensive gully and sheet erosion that is now taking place is primarily over-grazing by all types of domestic animals and partly annual fires deliberately started to improve the grazing.

The Railways Department has done excellent work in developing the various control measures, but, we understand, would like to be relieved of these extraneous duties. We recommend that this work be taken over in due course by a central Soil Conservation Service, to the setting-up of which we shall refer later.

(b) *Testing the effect of animal grazing.*

In the main it is considered that the soil erosion problem in the Red Sea Hills is not of sufficient importance to justify any considerable expenditure. At the same time the rapid deterioration of soil and vegetation now occurring at Erkowit is a warning that problems may develop elsewhere and we consider it desirable to obtain information as to the effect of keeping animals and fires out of the hills. We recommend that a patch on Jebel Awada in the neighbourhood of the Dris Pass should be fenced and fire protected and be left to see the effect on soil and vegetation, sample plots being examined once a year for plant population. We also recommend that a section be fenced off on Bawati and Elba for the same purposes.

(c) *Testing the effect of terracing the upper Khor Arbaat and of planting Acacia thereon.*

The flow of water into the reservoir at Port Sudan is now erratic owing to the nature of the rainfall at the head-water area of Khor Arbaat and possibly to rapid runoff from the catchment area. It seems worth while to terrace experimentally a strip of the catchment area and to plant up half the terraces to acacia, the remainder being unplanted in order to find out whether the flow to the reservoir could in this way be smoothed out. It is assumed that measurements of run off water would be taken.

(d) *Provision of wood fuel for Port Sudan.*

The town perimeter problem of Port Sudan is not at present of pressing importance, but a wood fuel supply would be appreciated if it could be arranged. We therefore recommend planting up a substantial acreage of mesquite on the coastal plain within easy distance of the town and also recommend planting up a smaller trial area to forest on the outwash fan of Khor Arbaat to seaward of the lowest wells of the pipe line in order to utilise water now going to waste.

Control and Development of Clay Plain Lands near Gedaref.

The Committee agreed that rain grown *dura* land is one of the most valuable assets in the Sudan and that any practical methods that can be devised for its preservation improvement and effective utilisation should be adopted. It was agreed that the first step should be the demarcation of village boundaries and the taking of powers to control the location of new villages under the Local Government Rural Areas Ordinance, so that harig lands might be developed with fire lines and water supplies to the best advantage of the people as a whole. Sheikh Abdulla Bakr gave it as his opinion that the minimum number of houses in a village in this area should be 25 and the maximum 300. It was agreed that plans for the development of this land should be worked out by the Governor or his representative with technical advisers for approval by the Soil Conservation Board on lines elaborated in this report rather more fully under harig areas of Blue Nile Province.

It was also agreed that the Atbara River pipe line scheme of development should be revived. The Soil Conservation Board should arrange for a line of trial bores to be sunk from the river to the railway at Qala en Nahl, passing near Doka. Should water from bores prove to be inefficient or saline, then the question of putting in a pipe line should be examined in detail.

C. KHARTOUM PROVINCE.

The Committee agreed that the town perimeters of Omdurman, Khartoum North and Khartoum are out of control, that the same is true of the up-stream end of Tuti Island and that in order to mitigate the dust and haboob nuisance and to provide adequate food supplies for the milch goats and sheep now kept in the three towns steps should be taken to bring these perimeters under control.

The up-stream end of Tuti Island is now covered with active silt dunes that are a source of drifting dust in the western half of Khartoum and the shore line at this end is in need of fixing by the planting of trees. These steps can only be taken if the area is first acquired by Government and we recommend purchase. The dunes would be most easily controlled by installing a pump scheme commanding the island as a whole. The Committee is advised that the now unused irrigable lands are required by the Director of Agriculture and Forests to provide experimental lands for the School of Agriculture and that the Governor of Khartoum wishes in the interest of good government to purchase the Island and to resettle the residents of Tuti village. It is clear therefore that the best procedure will be to purchase the entire island and to undertake the reclamation part of the projects so soon as a pump scheme has been installed.

The grazing of animals within the town perimeter of Khartoum North should be prohibited. It is essential that cheap fuel be made available for the residents, but we consider that this should be provided by railing from Suki. It is also necessary for dry fodder or grazing to be provided for the present goat population which provides milk for the poorer classes. The Governor recommends that a small pump scheme be installed to the east of the railway for the purpose of providing the fodder required. The land is known to be poor but an area could probably be found sufficiently good for this purpose. We support this in principle and recommend that the Governor be invited to put up a concrete proposal.

The Omdurman town perimeter should likewise be closed to graziers. Wood fuel should be brought by rail from the Suki neighbourhood. It was agreed that forage for the present goat population should be provided on a fee paying basis at a forage farm probably situated on the mud flat above the Omdurman Bridge, this being cropped from November to July and silage or dry fodder prepared for use in the high Nile season. The Governor has undertaken to go into this and to put forward specific proposals in due course.

It seems possible that water from such streams as the Khor Abu Anga might be used for cultivation if suitably spread and we recommend a test experiment. Should this be practicable, such streams could be used to ease the forage supply position particularly in the months of the high Nile.

From the point of view of dust control an experiment is recommended designed to find out what happens when animals are kept out of the town periphery. It would suffice for this purpose to fence in a segment of the Omdurman perimeter including a complete part of the Jebel Markhiyat catchment area from the watershed to the Nile and we recommend that this be done.

The Khartoum perimeter problem is a much bigger one and is more urgent. We agree in principle that the only real solution possible is to install a pump in the neighbourhood of Soba and to canalise an area between the Blue and White Niles for the general purposes of dust control and of providing forage at cost for the goats, sheep and donkeys now resident in Khartoum. It is agreed that a belt of trees should be planted to the south of the main canal.

This pump scheme to be based on Soba should be large enough to provide water for Khartoum gardens and street trees and for a water-borne sewage system and we have therefore asked the Governor Khartoum to go into this matter with the Town Planning Board, the Municipality and all Committees and Departments interested so that a unified scheme can be worked out designed to satisfy all requirements. When the Governor has been able to produce a unified scheme we recommend careful consideration by the Soil Conservation Board and that if it is found to be practicable that part of the expenditure that would be required for perimeter control be met from Soil Conservation funds.

Some General Points applicable to the Three Towns.

In general it was agreed that in order to make it possible to control the growing problem of town and village perimeters it was necessary to assume that the rights of citizenship should be deemed not to include the right to graze. Any legal action required should be taken.

Municipalities should provide controlled grazing on a fee-paying basis (with suitable relief for the poorest people) for the number of animals now normally present and considered to be essential to the life of the community, particularly donkeys for riding and as beasts of burden, and sheep and goats required for the supply of milk to the poorer people. As built-up areas and human populations grow, the goats, sheep and donkey populations should not be permitted to grow with them and additional milk supplies should be obtained by the development of dairies based on local cattle, kept outside the towns.

Access to approved grazing areas should be by authorised routes planned with dust control in mind.

Fuel supplies for the three towns could not possibly be obtained from the perimeter area and railed supplies from the Suki area must be the basis for some time to come. It would however greatly ease the situation to arrange for substantial areas of sunt forest to be established on the extensive and largely unproductive clay flats subject to annual immersion for several months situated along the White Nile up-stream of Omdurman and we recommend that 10,000 feddans of this land be expropriated and planted up either by the Department of Agriculture and Forests or by one of the Municipalities and be worked in rotation so as to produce the cheapest possible fuel supplies for the three towns.

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D. Blue Nile Province.

The Harig Areas.

In general it was agreed that the harig areas of the Blue Nile Province were of great potential value and that active measures should be taken to develop them on the basis of planned management with adequate arrangements for fire control and for the provision of water supplies.

It was noted that the Agriculture and Forests Department, with the School of Agriculture taking a leading part, had successfully developed measures of control from 1941 onwards and that 150 square miles of dura and simsim land had been protected for planting in 1943.

It was also noted that the Government had agreed to purchase heavy agricultural machinery with which to test the possibility of development of these lands for food production with the maximum possible use of machinery.

We recommend continuing and extending the work commenced by the Department of Agriculture and Forests and putting it on a permanent basis.

Clay-plain Lands for Settlement.

There are also great areas of the clay plain not yet brought into use chiefly because water supplies are not available and we recommend that serious consideration should now be given to the planned development of these areas. The most important areas are the parts of the Fung and Rufaa Districts which lie along the river from the northern boundaries of the province to Roseires, including the Dinder from its mouth to Durraba. We recommend that selected parts of this area should be chosen for planned management.

Action of several different kinds will be required.

In the first place, while no changes in land tenure may be required this question should be examined and clarified and any changes found to be necessary effected. The rights of nomads particularly need clarification and in general we are of opinion that in the event of a conflict of interests arising between nomads and settled communities it is in the interests of the permanent well-being and development of the Sudan that the rights of settled communities should prevail and that nomads should be excluded from all areas to be settled.

The next step should be an examination by a competent authority of the water supply possibilities of areas under consideration in order to ensure adequate water supplies in the areas finally selected.

The next step would be the demarcation of village boundaries to provide for holding the village at an approved size and for maintaining in perpetuity in good heart the lands of the village on a rotation designed to yield food crops in adequate quantity and variety, milk and meat, fuel and building poles.

The layout of existing and resettled villages should provide for the convenient centralisation of local services including administration, agricultural and vernacular education, public health, markets and shops.

Finally, it would be necessary to make adequate arrangements for the prevention of grass fires. This problem divides itself into three parts designed eventually to interlock, namely a large grid system, a harig protection system, and a village system.

The grid covers vast areas of grass lands running into thousands of square miles. We recommend an experimental line perhaps 80 miles in length running eastwards from Qala en Nahl through Rashid and Doka to the Atbara river, and another along the south side of the railway from Showak to Suki. At first these lines will have to be of the wide type now in use for harig protection. It is hoped, however, that the heavy agricultural machinery now on order for harig dura production will provide an opportunity for designing a bank type of line consisting of one or two raised bunds that may be maintained annually and cheaply with heavy-duty road grading and agricultural machinery.

The protection of harig areas in blocks should be continued and extended. As the work develops fire lining should be laid out on a permanent plan so that in due course any given block would be cultivated in rotation at the climax of each grass cycle with the fire lines always in the same place. Once again permanent bunds made with heavy machinery are to be encouraged so that a satisfactory design can be developed and maintained cheaply without the use of large groups of labour.

In the riverain area of the Fung fire protection should be arranged by the Local Government authority providing wide fire-protection lanes along the north-south motor roads and also along the east-west roads from village to river.

It will be impossible to select an area of resettlement until the water question has been dealt with and in the first instance we recommend putting down a trial line of about four fairly deep bores between Abu Naama and Renk, where the rainfall of approximately 500 mm. is optimum both for rain grown dura and for simsim. Should supplies prove inadequate or saline, then the possibility of installing a pipe line supply from the Blue Nile should be considered.

Control of Soil Erosion.

A good deal of soil erosion has taken place within historical times in those sloping lands bordering upon the Blue Nile from Khartoum to Roseires. From Sennar to Roseires these lands are estimated to be carrying an adult male population of 40,000. This is considered by Mr. Hancock, who is particularly familiar with the area, to be twice what the existing villages can properly carry with due regard to soil conservation and permanency. The erosion is due to over-cropping, to the cumulative effect of too many goats and sheep, and to cutting of wood for fuel within the village perimeters. What is required is resettlement on a considerable scale on alternative livelihood schemes coupled with a planned management of both the new and the old villages so as to achieve permanency.

E. KORDOFAN.

This will be considered under the following heads :—

Camel breeding, gum producing, northern agricultural areas, Nuba Mountains agricultural areas, and town and village peripheries. The soil conservation problem varies widely in these five types of country.

Camel Breeding Areas.

Because the sand dunes characteristic of so much of the northern part of Kordofan are static and have been so throughout historical times, there is no problem of desert creep to deal with so long as present populations are not exceeded. The information about this area is meagre but what is available indicates a condition of natural balance and we do not consider that any soil conservation measures are required.

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[illegible]duction Areas.

[illegible] areas represent a very considerable capital asset now under inadequate [illegible] supervision. To remedy this unsatisfactory position and to enable a com- [illegible] plan to be made we recommend the appointment of a Conservator of [illegible] a period of ten years to study in collaboration with Province Staff the whole [illegible] gum production problems, to design and lay out with the assistance of G.R.F. [illegible] of experiments to follow up the work already done and to afford a factual [illegible] the eventual plan, to conduct these experiments and eventually to submit [illegible] suggesting the main lines on which planned management of production [illegible] be encouraged.

[illegible] Agricultural Areas.

[illegible] are intimately related to the gum areas and suffer from the same lack of [illegible] technical information to enable recommendations for management to be [illegible] It is known that soils are often poor and that rainfall is erratic. With such [illegible] planned management based upon adequate factual information is [illegible] to ensure a balance being maintained between water supplies, density of [illegible] and agricultural soils so that the life of the community will be on a basis [illegible]tinuity.

[illegible] order to obtain the information required we recommend establishing an experi- [illegible] area approximately 10 miles long in an east-west direction within reasonable [illegible] of the Kosti to El Obeid railway.

[illegible] agreement with the local administration, villages within this experimental [illegible] able for and willing to accept planned management would be selected with [illegible] to testing the sort of management of agricultural and gum areas considered [illegible] to succeed on existing information.

[illegible] the experimental area the existing water supplies would be put in order and [illegible] supplies established where necessary.

Whether or not east-west fire lines would be required will depend upon the site [illegible] but if required they should be established.

[illegible] same applies to east-west belts of forest trees such as neem. If required [illegible] would be established along the northern boundary of the experimental area.

[illegible] suggested that this experimental area be managed by an ad hoc Com- [illegible] consisting of the District Commissioner, the Senior Inspector of Agriculture [illegible] Chief Conservator of Forests or his representative, who would report not [illegible] than once a year to the Conservation Board.

[illegible] Mountains Agricultural Areas.

[illegible] is one of the areas in the Sudan where active gully formation and soil [illegible] taking place, particularly between the terraced hills and the plains below. [illegible] that the Berdab area, where cotton cultivation has increased the rate [illegible] be used as a centre for reclamation, at first on an experimental [illegible] contour bunding by heavy machinery and contour planting of grass [illegible] done on a large enough scale to give an indication as to which is [illegible] point of view. We visualise that one tractor unit operating [illegible] required in the first instance and that further work would [illegible] results obtained.

[illegible] of the Nuba Mountains lend themselves to comprehensive schemes [illegible]

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(a) The reservation of the upper part of a catchment area as a forest reserve.

(b) The construction of a dam across a stream so as to impound water.

(c) The settlement of new land on the plain below with domestic supplies drawn partly from the water impounded.

(d) The drainage of water-logged areas.

(e) The preservation of the areas by contour bunding.

We recommend that the Kinderma area be investigated to see if such an experimental or pilot scheme could be developed and at what cost.

Should such a scheme prove to be impracticable at this stage then we recommend an experiment designed to protect from annual fires one substantial hill valuable as a water catchment area. The measures required will depend upon the hill selected, but both human beings and fires would have to be excluded. As fire lines at the base of jebels are difficult to maintain, it is recommended that belts of living forest or vegetation selected for their fire barrier qualities, and bunds of shape and size to prevent the passage of fires should be tried to find out what method would be cheapest and best from a long term point of view.

Water supplies for rural communities in the Nuba Mountains are often scarcely adequate for present needs and in places such as Talodi where population has increased the supplies are already beginning to fail. It is clear that all well systems and rock cisterns in the Nuba Mountains should be examined by a representative of the Conservation Board with a view to their rehabilitation and protection and with a view to additional supplies being provided where required. It may well be that a good deal of catchment area preservation may be required as a result of this examination.

With a view to avoiding soil deterioration due to land pressure as populations increase we consider it desirable for the Governor to review this matter annually and to include a statement for record in the Annual Report of any areas in which this problem shows signs of developing.

Planned management of village lands on a rotational basis so as to avoid uneconomical fragmentation and overgrazing should provide the remedy, coupled with the development of alternative livelihood schemes in the form of new agricultural villages for supernumerary population. Details can, however, only be worked out locally and the Governor is the most suitable person to put up plans for any action that may be required.

Town and Village Peripheries.

As El Obeid is so much larger than any other town in Kordofan an ad hoc Committee was set up to make recommendations for the control of the town perimeter. In this case the existence of the town with its need for food, forage and fuel supplies caused the static goz to become active close to the town, soil deterioration as shown by the larger areas now clothed with the Ushur bush (*Calotropis procera*) within a ten-mile radius, and a marked deterioration of the forest within a 30-mile radius.

The Committee consisted of the Governor as Chairman with the Senior Inspector of Agriculture, the Senior Medical Officer, Mr. March and Mr. Marjoribanks as members. A valuable report, attached as Appendix XIV, was submitted. This has now been agreed to by the Town Council and both in principle and in detail by the Conservation Committee. We recommend adoption of this report and wish to express our thanks to Mr. Campbell and his Committee for the excellent work done.

All other town and village perimeters in Kordofan should be dealt with on similar lines as these are the areas where human beings through natural processes unconsciously convert static surface into active sand and eventual desert unless checked by methods now known to be both practicable and effective. We suggest that the Governor sets up ad hoc committees to make recommendations for dealing with the perimeter problem of the large towns, and that the D.Cs. in collaboration with Agricultural Inspectors, co-opting Medical and Forestry staff as may be required, deal with those of the smaller towns and villages. In all cases there should be: a basic town or village plan of development with maximum population of built-up area fixed; complete control of grazing in the perimeter; provision of forage supplies for milch animals; and provision for fuel supplies and control of dust formation in the perimeter area. In the case of larger towns the provision of forage for milch animals is always difficult and arrangements should be made whenever practicable for the establishment of a dairy based on green fodder in the rains and on hay and concentrates in the dry season.

F. Darfur Province.

Dr. Tothill made an extensive visit to Darfur Province in 1943 largely to obtain a first hand idea of the soil conservation problem. His note on this aspect of the Province is attached as Appendix XVIII, and we agree in general with his conclusions.

Perimeter protection is required for all the towns, larger villages and important well centres. The position is much as it is in Kordofan and similar methods should be adopted to bring the perimeters under control. The first requirement is a town plan with control over extensions so that no town will be allowed to grow beyond the capacity of its water resources, its food production resources, its forage resources for essential domestic animals, including particularly donkeys and animals required for milk production, and its fuel resources. Having adopted a plan the next step is to bring the perimeter under control by the prohibition of grazing, the restriction of agriculture, and the planting of forests where required in such a way that the community will be able to have daily its fresh vegetables, its milk and its fuel. The best way to tackle this problem in Darfur would appear to be to set up an ad hoc Committee with the Governor as Chairman and with Medical, Forestry and Agricultural members whose duty would be to examine the situation at each of the larger centres and to make recommendations to the Soil Conservation Board and we recommend accordingly.

Apart from perimeter protection, Darfur Province is so well defended against erosion by the continental goz sand and by the terraces of Jebel Marra that nothing more is required to be done at this stage. Had it not been for the Jebel Marra terraces, the situation would have been entirely different and we take this opportunity of saying that in our view the ancestors of the present Mountain peoples conferred a priceless gift upon their descendents by constructing so admirable a system of protection against the impairment of the main catchment area of the Province. We urge upon the present generation the need for keeping this system of terraces in a state of good repair so that their children in turn may continue to reap the benefits.

G. Upper Nile Province.

This Province is so flat that there is little or no sheet or gully erosion. There is, however, a good deal of serious soil deterioration now contributing to impoverished food supplies and due in the main to over-working and over-grazing the established lands. These problems are related to the fact that domestic water supplies on good agricultural land are frequently inadequate.

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Planned management of village lands, the establishment of alternative livelihood villages, the provision of water supplies and the protection of harig lands are the directions in which progress is likely to be made and a good deal of exploratory work must be done before concrete proposals may be expected to emerge. Planned management of village lands will necessarily differ according to tribal habits and in the first instance we recommend that a small scale trial be made in each of the three main tribal areas occupied respectively by the Dinka, the Nuer and the Shilluk. The plan for trial in each area can only be evolved by Local Province and Agricultural staff familiar with conditions, with such assistance from the Soil Conservation Board as may be required. The essential would be (a) to fix the maximum size of the village and to make arrangements for new villages to come into being to take up supernumerary population, (b) to lay out the village lands on a rotation plan so that they can be expected in perpetuity to provide an abundance and variety of food and milk and so as to provide a cash crop, (c) to prevent the village lands being over-trampled and over-grazed by domestic animals, and at the same time to provide adequate grazing for domestic animals, (d) in the case of cattle-owning tribes to attempt to limit the numbers to be allowed to any one village and to hold them to the approved number by introducing a cattle improvement service consisting in the main of the provision free of cost by the Veterinary Department of a cattle health service wherever communities would agree to pay for it by the annual surrender to Government of male bulls. At the 1945 muster for instance a census would be made of adult bulls and cows. If at the 1946 muster the totals had increased the owners would hand over to Government the worst animals to the number of the increase. The culling of unsuitable female stock might come at a later stage and would depend on whether a stock improvement scheme could be developed so as to meet with general approval. The numerical control of cattle is a vital element in any long-term plan for maintaining village and outside grazing lands in good heart in perpetuity and we therefore attach considerable importance to devising experimentally ways and means of achieving this control.

The establishment of alternative livelihood villages, as has been done by the District Commissioner at Pengko, may prove to be possible on a fairly large scale. The sites should be chosen only after a water supply had been provided in an area of suitable land. Commencing from zero it may be possible to lay out these villages and their lands in a more or less ideal manner with the ultimate size fixed in advance, the lands laid out in compartments to provide a suitable rotation for the production in perpetuity of ample food and milk supplies and a cash crop, and with adequate provision for grazing for domestic animals and for fuel supplies. In the village itself or for village groups provision would be made for a council, ordinary and adult education, a medical centre, and a market, including shops.

The provision of water supplies will vary with the nature of the country but we consider that fairly large exploratory works should be undertaken in selected areas for the provision of supplies (a) by fairly deep wells or bores, (b) by the introduction of surface water through the clay surface into sand bed underground reservoirs, (c) by the development of surface water reservoirs both by the digging of hafirs and the damming of water courses.

As the provision of water supplies is largely a technical matter we consider that the Soil Conservation Board should arrange for a water survey and then maintain in the Province well-digging units, well-boring units, and a heavy machinery unit for digging hafirs and damming water courses.

Harig cultivation is practised in parts of this Province and we consider that it should be encouraged (a) by the installation of fire lines protecting blocks approximately one kilometre square and (b) by the provision of water supplies to enable harvesting to be done. In the first instance we recommend that someone from the

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Department of Agriculture and Forests familiar with this work in Gedaref and the Blue Nile Province be sent to the Upper Nile Province for one season to help initiate a survey of suitable areas and their protection by fire-lining. As the machinery referred to in the paragraph above is unlikely to have arrived it is probable that water supplies for the first year's protected harig lands would have to be arranged by the District Commissioner on the advice of the Soil Conservation Board in the form of hafirs, underground reservoirs of the Paloich type fed through shallow wells and deeper hand-dug wells.

H. Equatoria Province.

With the exception of some areas in the Nuba Mountains there is no part of Sudan where agricultural lands are being more heavily eroded than in the hilly parts of Equatoria Province both east and west of the Nile, and careful planning is required to enable these lands to be developed in such a way that they will remain in a state of good fertility in perpetuity and to preserve the main catchment areas so as to regulate the domestic water supply. We will discuss under the headings of (i) fire control. (ii) the preservation of catchment areas and (iii) development of agricultural lands.

(i) *Fire Control.*

At the present time most of the country is annually swept by fire and over great areas serious damage is done in the destruction of regenerating forest and of the soil itself and we regard these annual fires as a contributary cause of erosion. The area to be controlled is, however, so vast that no immediate comprehensive remedy is possible and all we can hope to do is work out a plan for gradual expansion, so that control may be achieved in the areas that matter most before it is too late. In the first place, we recommend in all areas where fire exclusion is impractical that early burning be encouraged by Provincial Staff in order to reduce the proportion of severe burning. It is not easy to fix habits of early burning in the minds of a population and it cannot be done in a day, but a fair measure of success has been achieved in parts of Nigeria and Uganda, and it seems worth a serious attempt, particularly in the Lulubа hills and the Nile-Congo Divide areas. Secondly, we consider that a compartment type of control with fire lines should be the long term aim. In the area between Yei and Yambio there are many streams running north which might form the basis for a grid system and there are a few roads running east and west; the roads do not prevent a fierce fire crossing, but could be used as one edge of a fire line to be burnt annually so as to form a wide barrier at the time of the main fire hazard. We recommend that an experiment be conducted by Province Staff at a selected place designed to enable roads to be converted into fire protection lines, that advisory assistance be given by someone familiar with harig protection work, and that funds for the experiment be provided by the Soil Conservation Board.

(ii) *Catchment Areas.*

While nothing can be done to improve the rainfall, there are sound reasons for supposing that a good deal could be done to regulate the flow of water in springs and streams by exercising control over their sources. Agricultural development tends to creep into catchment areas and as this automatically impairs the water supply by increasing run-off we recommend in the first place that a survey be made of the sources of all the main streams east and west of the Nile with a view to making them forest reserves for catchment control wherever this can be done. Reserves when created should be delimited and marked with beacons and surrounded and criss-crossed with fire lines where this may be necessary.

In forest areas and around the bases of hills it seems possible that permanent fire lines might be created by planting to trees, bushes, or herbage plants that from habit of growth naturally form fire breaks. We recommend that the Chief Conservator of Forests in collaboration with the Senior Inspector of Agriculture should lay down a series of experiments designed to furnish factual information on this point. These experiments should be scattered so as to represent the main soil types and rainfall belts, as one would not expect one type of vegetation to suit all conditions. Funds should be made available by the Soil Conservation Board.

Because there are so many isolated hills in this Province all of which serve as catchment areas for local springs either actual or potential, and because they are normally overrun by fires which reduce their water holding capacity, we recommend that these experiments should include at least one fair-sized hill which would be gazetted a forest reserve and demarcated. It would be necessary to keep human beings, particularly honey gatherers and hunters, out of the reserve area, as well as fires from the plain below.

The Imatong Mountains constitute the most important catchment areas east of the Nile. We strongly support the forest reserve plan already agreed between the Director of Agriculture and Forests, the Chief Conservator of Forests, and the Governor, and recently modified at the suggestion of the District Commissioner and Mr. Vidal Hall. In our opinion the pace of the execution of this plan should be accelerated so as to head off agricultural infiltration and to remove cultivators already established at vulnerable points. It would be proper to devote Soil Conservation Board funds for the purpose of accelerating this programme.

(iii) *Agricultural Development.*

This may conveniently be discussed under existing areas and new schemes.

While we recognise the substantial medical reasons, involving the saving of human lives, that prompted the Government to move populations away from streams inhabited by the insect vectors of Sleeping Sickness and local *Simulium* river blindness, it is none the less a fact that some populations were moved to areas where soils are unsuitable and water supplies inadequate. We recommend that wherever the Senior Agricultural Inspector, Juba, is satisfied that a particular community is badly settled the Governor should set up an ad hoc Committee with the District Commissioner, the Senior Medical Officer, the Senior Inspector of Agriculture and the Government Geologist or his representative as members to endeavour to find more suitable lands where water supplies can be made available and that steps be then taken to move the people to these lands.

Some existing areas could be put on a permanent basis by introducing uncultivated grass strips on the contours. We recommend that all District Commissioners should, in consultation with the local Agricultural Inspector, cause this method of strip cultivation to become routine practice throughout their district. No expenditure of funds is required but persuasion and patience will be needed to bring strip cultivation into general practice. At a later stage this work would be supplemented by the building of contour bunds.

We understand that all farms and experimental plots operated by the Agricultural Department in the Province have now been provided with contour bunds and with this policy we are in complete agreement. We consider that garden or other plots controlled by all branches of the Government and by missions should for the sake of example be operated on the contour strip plan and be provided also with contour bunds.

Any new projects in the agricultural areas of the Nile-Congo divide should be laid out with due regard to soil conservation. Strip cultivation should be made universal in such areas and such contour bunds should be provided in the beginning as may be considered by the competent authority to be essential for control.

There are a few permanent or nearly permanent streams west of the Nile and it seems that use might be made of these for cultivating limited areas under irrigation in the dry weather. With a view to testing the usefulness of such a development we recommend that a small scheme be laid out with an irrigation canal about ten kilometres long. Such a scheme could probably best be introduced in connection with the economic development programme now under consideration by the Government for the Yei to Yambio area. We visualize that the details of the scheme would be settled by the Governor as advised by the Senior Inspector of Agriculture, the Senior Medical Officer and the District Commissioner and that the works would be constructed on the advice of the Soil Conservation Board. In the event of success, similar schemes would be initiated and the work extended to make the best use of streams that dry out for some months in the year, due regard being paid to the rights and protection of water users down-stream.

Young, R. and H. Fosbrooke. 1960. Smoke in the hills: Land and politics among the Luguru of Tanganyika. London: Routledge and Keegan Paul.

Preface

The seeds of the changes overtaking Africa were planted many years ago, even with the development of "Indirect Rule," when the dynamics of modern politics were injected into traditional political systems. Everywhere (or almost everywhere) the old patterns of society, the old political controls which governed people's lives, are being modified by challenging new demands. The Western world with its special types of political institutions, its technical knowledge, its standards of competence, and its emphasis on the value of the individual has promoted dissatisfaction with the old political order, and demand for change comes from within African society itself.

As change comes, the older methods of controlling society may be less than satisfactory, but the newer methods may not please everyone. Political crises may occur when change does not bring stability or satisfy the people, a point discussed later in the crisis over land terracing in the Uluguru Mountains. Not everyone favors change—or change at the same rate and in the same direction—and new ideas and methods may be resisted by those who feel themselves threatened. There are conflicting sets of norms, and the value to be given to each, of deciding what aspects of the modern should be adopted and what aspects of the traditional should be retained, raises problems that have no obvious solution.

Africa is everywhere facing a political problem, now further accentuated as the reins of overseas colonial control are slackened and increased authority is assumed by African political leaders. That problem is one of establishing political institutions that are efficient, stable, and integrated effectively with the society they

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control. What is new requires development, and what is old may need modification.

The above generalizations are applicable for much of Africa. In this study local and specific examples will be given of what occurs when Western ideas of politics and technology are introduced to an African society having relatively simple political institutions. The people are the Luguru who live in the mountain area of the Morogoro District in east central Tanganyika. The selection of the Luguru as a subject of study was in some ways particularly fortunate. Their system of indigenous authority has continued into modern times and enables one to examine at first hand the traditional controls in the society. Traditional authority was decentralized and segmented, based on lineage, with descent passing through the mother's line. This indigenous system of control has in more recent times been supplemented by a type of local government known as Native Authority. The expression "Native Authority" has in some places come into bad repute, and in official documents it is being replaced by "Local Government," which in turn is often ambiguous. However, the law still refers to Native Authority, Native Treasury, and Native Courts, and those terms are used customarily and without embarrassment in the Morogoro District. The introduction of Native Authority is of special interest because it reveals some of the difficulties encountered in creating for an African society a type of local government based on Western principles. The new and the old live side by side. Problems are raised concerning personnel, such as the extent to which the holders of traditional office can be used in the new organization. Problems are also raised concerning the nature of the responsibility of this new organization, and of how the new techniques of votes and elections blend with the more subtle controls found in the older systems.

The selection of the Luguru for study was fortunate for yet another reason: it provided an opportunity for comparing the attempts of government, of the old and the new, to control the environment. In the Uluguru Mountains the dependency of man upon his physical environment is strikingly illustrated, for there the people live close to the soil and are dependent on it for existence. The striking beauty of the mountains, rising impressively from the plains and providing a cool haven from malaria, is not matched by

the productivity of the soil. The land is poor, and demands are placed on it to support an increasingly larger population. The Luguru are attached to the mountains and prefer to live there, even with thin, eroded soil and poor crops, than to migrate to the hotter plains in the lowlands where land is still available.

The Luguru political system attempts to control the physical environment and, in particular, to allocate land for the use of its members. The newer Western government is also interested in controlling the environment. With land so badly eroded, Government decided that drastic measures were needed if the mountains were to continue to support life, and a program of soil conservation was introduced, with emphasis placed on the construction of bench terraces.

During the period in which the district was "under observation," political riots developed in protest against this conservation program and they reached such intensity that the terracing program was eventually abandoned. The crisis revealed in dramatic form the conflict that may arise when new, unwanted agricultural methods are introduced and also the nature and cause of the resistance. It also revealed some of the difficulties involved in creating a government capable of leading the people along new paths and at the same time commanding their support. One aspect of the crisis was the claim for power made by rival groups; on the one hand was Native Authority, partially integrated into Luguru society and using modern methods of administration, with the ultimate sanction over their actions lying with Central Government. On the other hand was the opposition, led by a hereditary rain-maker (or by his cousin), and appealing to tradition and the old way of life. A second aspect of the crisis was the conflict which developed between the technical proposals and their execution in the field. It was necessary to find technical solutions for controlling and improving the land, but the administration of the policy under African conditions proved to be especially difficult.

Before the crisis developed, the district seemed to be passive and tranquil, but it was shortly cleft by anger, confusion, and divided allegiance as the Luguru rejected some of the imposed solutions for their economic difficulties. Once the surface tranquility was broken, there was a general deterioration of political order, and au-

thority was challenged on several fronts. One man was killed during a demonstration against compulsory terracing. Agricultural instructors, attempting to discuss rules for soil conservation, were shouted down and threatened with physical violence. A blanket of smoke covered the Uluguru Mountains. This was a symbol of defiance, a warning that the farmers were fed up with rules of conservation and that they would burn their land despite regulations to the contrary. The new methods were not for them. Several platoons of police were brought in to restore order, and most of the district was declared a troubled area. In the face of this resistance, the Government gave in, abandoning the program of soil conservation. Even after three years, terracing evoked strong emotional reactions and the word itself was not used officially. Many of the terraces that had been constructed with such hard work had been pulled down.

Although the problems of the Morogoro District differ in degree from those found in other areas, an understanding of these problems may be of assistance in understanding the complexities of political life in other parts of Africa. By concentrating closely on this microcosm, one may get a clearer view of the nature of the challenge to African society when the whole continent is caught up in a torrent of change. This challenge is not primarily racial, of white against black (although it may be so manifested on some issues). In the major issue facing the Luguru people—the utility of their political institutions in meeting modern demands—the racial question as such is not significant. The primary conflict is cultural, here centered on differing methods of organizing society and establishing controls, on differing goals and systems of ideas, and on the application, or even the applicability, of differing technical skills.

It may be helpful if some simple definitions and identifications were given at this point. Luguru is the name given to the people: they are otherwise and more widely known as the Waluguru, but in keeping with current trends in orthography the Bantu prefix *wa* has been dropped. The root word *guru* means hill or mountain; and Luguru, being an augmentative, is basically a geographic expression meaning "the people of the big mountain." The word Uluguru describes the areas where the Luguru live, the prefix *u* meaning simply "the place of." Morogoro is at once the principal town in

the district as well as the name of the district. The application of this name to the town and district is of recent origin and, on inspection, can be seen to be also a derivative of the root word *guru*. Following the Bantu practice, an inhabitant of the area would be known as Mluguru, and, with the "l" and "r" frequently interchanged in the Bantu languages (the Uluguru Mountains are labeled "Uruguru" on early maps), the base word may have been corrupted into "Mruguru" and so to the present-day "Morogoro."

The designation of a tribe when applied to the Luguru presents some difficulties, for traditionally the smaller unit of the clan, and the still smaller unit of the lineage, were the principal groupings which exercised internal controls. There was no over-all tribal organization existing before the arrival of Europeans, and the people were indigenously a segmentary, chiefless society with the concept of tribal unity being virtually non-existent. The "Luguru chiefdom" is a European-inspired term, and the offices bearing such attractive titles as sultan, mtawala, liwali, and jumbe have been newly created.

This study is based on the work of the two authors who independently, at different times, and for somewhat different purposes, observed the political life in the Morogoro District. I was drawn to the area because of my interest in the development and transition of political institutions, and Morogoro was selected because it represented a middling-type district, neither as rich or progressive as some nor as isolated and traditional as others. Mr. Henry Fosbrooke (who is now Director of the Rhodes-Livingstone Institute for Social Research at Lusaka, Northern Rhodesia) came to the district at an earlier period in connection with his work as Senior Sociologist of the Tanganyika Government. Some time after the individual ventures were initiated, we discovered our mutual interest and concluded that a joint work combining the ethnographical and the political material would tell a more complete and satisfying story than either published independently.

The Tanganyika Government has been uniformly co-operative in assisting us to carry out this study; they have proferred information, opened files, granted interviews, answered inquiries, and in other ways assisted and expedited the preparation of the materials. We would like to express our thanks to the Tanganyika Govern-

ment for their co-operation as well as for their kindness in granting permission to publish materials, some of which were collected originally for official purposes. The Department of Lands and Surveys has very kindly granted permission to reproduce the tribal and ethnographic map of Tanganyika. We are also indebted to the Program of African Studies of Northwestern University for material assistance in the field; and special thanks are due the Director, Professor Melville J. Herskovits, for his interest in the project and for the encouragement and support he has given in carrying it out.

In developing this study we shall first survey the Western innovations that have fostered change in the political system of Tanganyika. This will be followed by three chapters describing the physical environment and the Luguru social structure. The study will then consider how, and with what success, the Western political institutions have been introduced. A single chapter is devoted to the experiment in land reform undertaken by the Uluguru Land Usage Scheme (ULUS). A final chapter makes some concluding remarks and advances some recommendations. Mr. Fosbrooke is the author of Chapters III and IV and shared in the preparation of Chapter II and the Appendixes; and each of us has read and commented on the work of the other.

March, 1959 ROLAND YOUNG

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VII

The Uluguru Land Usage Scheme

The development of the Scheme

Shortly after the Second World War, the Uluguru Land Usage Scheme, or more familiarly ULUS, was developed for improving the land in the Uluguru Mountains. The Scheme was not completely accepted by the Luguru, even though it gave promise of a higher standard of living, and in 1955 there were riots over compulsory terracing. One man was killed; the Luguru chiefdom was declared a disturbed area; and police were called in to re-establish order. In the years since the riots many of the terraces constructed with such hard work have been pulled down and the word "terrace" expunged from the official vocabulary.

The Uluguru Scheme is of singular interest to this study because of the nature of the unresolved conflict over improving the physical environment of the Luguru. The following factors were involved in the conflict: 1) the traditional system of Luguru authority, and in particular the method of allocating land; 2) the administration of the scheme by the District Office and Native Authority; 3) and the technical recommendations for preventing erosion. The traditional system of allocating land has been described in earlier chapters, where it was shown how the organization of Luguru society is closely related to the control it exercises over the physical resources of the country. The organization of the District Office and of Native Authority has also been discussed. There remains to be considered the technical proposals that were offered as a solution

for land and water conservation. The Luguru by and large rejected the proposals: they objected to the hard work involved certainly, but more deeply they feared that the Luguru way of life was being threatened by the land reform.

Agriculture and forestry officers had been aware for some years before the Scheme was adopted that the Uluguru Mountains were carrying a heavier population than the soil could sustain. The land was eroding, and as the Luguru extended their holdings in the hills they destroyed the forests. This in turn had a harmful effect on the supply of water in the valleys, inasmuch as the headwaters of several of the major rivers of Tanganyika are located in the Uluguru Mountains. It was feared that, if these headwaters were not protected, the rivers in the valley would change from permanent to periodic rivers with characteristic flash floods and silting. In retrospect, some of these fears may have been exaggerated, but there was little doubt that the productivity of the land was low. There was no additional land available in the hills, and, if conditions continued as they were, there would be further loss of soil fertility and a lowering standard of living for the Luguru.

The chief proponent of conservation measures was Mr. A. H. Savile, the Regional Assistant Director of Agriculture, who was greatly concerned about the deteriorating conditions of the land in the Uluguru Mountains. In explaining the background of the land crisis, Mr. Savile wrote that the Luguru left the plains about the year 1884 to escape the attacks of the Ngoni raiding parties and took refuge in the forests of the Uluguru Mountains. Once there, the Luguru "preferred the cool and healthy climate in the mountains" to the alluvial plains, and "they then proceeded to destroy the land on which they were living." Additional land was cleared to meet the growing demands, and the abandoned land was not permitted to rest long enough to regain its fertility. Steep slopes were cultivated without protecting the soil from surface wash, and "the fertility of the land was rapidly destroyed due to the removal of the surface soil by sheet erosion." The vicious circle proceeded: over-use of land; erosion; expansion of cultivated land; more erosion. Mr. Savile found in 1947 that the stage had been reached "when a family has to cultivate four or five times as much land as was necessary thirty years ago. . . . Sheet erosion has advanced so

far that, in many cases, the natives are endeavouring to produce crops on clayey subsoil underlying a surface layer of two or three inches of immature surface soil."

African planters near Bagomoyo were affected by the change in the flow of the Ruvu River, Mr. Savile said. Prior to 1929, the planters could live and cultivate their crops on the alluvial soil throughout the year. Subsequently, the flooding of the rivers was frequently so excessive that the planters could not cultivate during the wet season. Similarly, the reduced flow of water in the dry season affected the cultivation of rice in the creeks adjoining the river. The Africans had formerly grown rice by means of tidal irrigation; the Ruvu River would be banked up against the spring tides, flooding the creeks with fresh water. Many of these creeks were now flooded with saline water because the reduced flow of the Ruvu during the dry season had resulted in the encroachment of tidal sea water.

Mr. Savile thought it was safe to predict that the position in the Uluguru Mountains would get very much worse "unless the problem is tackled on a large scale in the near future." Even with complete erosion control, he thought it "improbable that the mountains will be able to carry all the population at present living there and it seems certain that eventually a large proportion of the population will have to be moved down to the plains." [1]

Some parts of the Savile argument might have been modified, given additional evidence. Mr. Savile was mistaken in his belief that the Luguru had arrived in the Uluguru Mountains as recently as 1884; ethnographic research carried on subsequently shows that the Luguru have lived in the hills for some 300 years. This long tenure may have given the Luguru greater accumulated knowledge of their soil than the experts realized, and it is possible also that the rate at which the population was expanding, the soil was deteriorating, or the forests were being destroyed, was not as great as Mr. Savile believed.

The evidence on the extent of sheet-erosion is difficult to acquire;

[1] From memorandum, "Soil Erosion in the Uluguru Mountains," by A. H. Savile, Senior Agricultural Officer (1947) (typescript); see also Mr. Savile's article, "The Study of Recent Alterations in the Flood Regions of Three Important Rivers in Tanganyika," *East Africa Agricultural Journal*, XI, October, 1945.

although Mr. Savile may have been right in his judgment here, the evidence may also be interpreted to mean that sheet-erosion was not appreciable or was not due primarily to Luguru methods of agriculture. There were memorable flash floods in the Uluguru Mountains before 1884, the year selected by Mr. Savile for the entry of the Luguru into the hills. The explorer, Henry Stanley, records at considerable length a description of the damage inflicted by the great flood of 1871, when whole villages were washed away. In Tununguo, on the eastern side of the Uluguru massif, Mr. Fosbrooke has been shown stratified layers of mud from previous floods; some of these great floods were named and remembered in tribal tradition from periods long before the population pressure had reached its present density. If sheet-erosion had been followed by heavy silting, changes in the flow of the Ruvu River might have been expected; however the records (albeit incomplete) of the East African Railways do not indicate any real change in the flow at Ruvu Crossing since the railway bridge was built by the Germans near the turn of the century.

The details of the arguments are noted inasmuch as they affected subsequent policy, particularly the definition of the problem to be resolved and the urgency of the remedy. Despite the points in the argument to which exception may be taken, the Savile statement on the deteriorating condition of land in the Uluguru Mountains was forceful and persuasive, and it formed the official rationale for establishing the Uluguru Scheme. On the broad question of conserving the soil and increasing the fertility of the soil, there could be little doubt that the Luguru would benefit by the application of available technical knowledge. They were then living at the level of marginal subsistence, with an estimated average cash income of 70s. ($10) a year. In 1947, £50,000 was made available from agricultural development funds to be spent over a ten-year period in rehabilitating the Uluguru Mountains.

The Scheme got off to a slow start. Significant policy questions had first to be decided, since the proposal for the grant had been drafted only in general terms. Several plans were discussed by the administrative officers from provincial and district headquarters and by the technical experts from agriculture and forestry. The Forestry Department proposed to remove barren land from cultivation and plant it in trees, with the upper area of the highlands demarcated as a special reserve for protecting the headwaters of the streams. An agriculture officer proposed that major emphasis be placed on terracing; demonstration plots would first be built, and the Luguru would have a full year in which to decide whether they would accept this plan. Objection was made that the delay would prevent the Scheme's being completed within the ten-year period.

In the end it was decided to spend the bulk of the money on personal emoluments for staff and to concentrate on the development of bench-terraces as the most effective way of preventing soil erosion. It should be said here that there was not complete agreement among the technicians on the utility of bench-terraces and that from time to time during the life of the Scheme the policy was criticized. Nevertheless, the policy of bench-terracing was followed, often inflexibly and to the exclusion of other methods. Earlier plans spoke of the desirability of constructing demonstration areas, but it is one of the misfortunes of the Scheme that such areas were not developed to a point where they could be shown to the Luguru as a model way of farming in the highlands. Some of the technicians also thought it unnecessary to construct experimental plots; time was short, and besides, it was said, "only proved methods would be used" in the Scheme. Another reason was that unproved experiments might result "in partial or total failure of the crop, thereby undermining the confidence of the Waluguru." But not all were satisfied, and some technicians complained that the emphasis on bench-terraces restricted the Scheme to methods used elsewhere "to the complete exclusion of experiments in the light of experience."

Further experimentation seemed desirable, for there were indications that bench-terracing was not always effective. In an area constructed for demonstration purposes in Morningside (south of Morogoro) in 1949, the terraces turned out to be completely sterile. The annual report stated laconically that the setback "has been overcome by careful and prolonged propaganda and the posting of two extremely intelligent instructors to that area."

The administration of the scheme was placed in charge of a district officer, and he was assisted by three to four agricultural field

officers. The latter, in turn, were in nominal charge of the several score African agriculture instructors who were employed on the Scheme. The official work was primarily educational and supervisory; explanations were made as to why the land was washing away, and the necessary steps were suggested for reclaiming the land. A series of bush schools were held at the village level to instruct the farmers in recommended methods of terracing, and meetings with headmen were held once a month. African agricultural instructors were trained in the techniques of soil conservation and were sent in the field to assist in the program. Terracing was made mandatory, and farmers were not permitted to burn the trash and weeds on their land without permission. Rules on the proper care of land were adopted by local councils and were enforceable in Native Courts.

As time went on, a hostile reaction developed to the new agricultural techniques, or to their implications; the hostility was expressed through unauthorized political channels and eventually led to intimidation, open violence, and the use of force. The new techniques were a challenge to the traditional methods of farming, where the hoe and the machete were the major pieces of agricultural equipment. They were also a challenge to the general social structure, for the new regulations did not depend for their effectiveness on voluntary compliance alone and required additionally the use of Native Authority, which was capable of making binding rules. The subsequent disturbances may be considered to be a form of resistance not only to the new farming techniques but also to the imposed rule which introduced and supported them. In all, the plan embodied in ULUS raised some issues which disturbed the Luguru greatly, for it struck at two sensitive topics: the land and, beyond that, the social system which governed the use of the land.

The solution of opening up new land and then coaxing, persuading, cajoling, or bribing some of the Luguru to move there was a tenable proposal so far as the availability of land was concerned. However, the Luguru were generally reluctant to move to the plains, which were associated with humidity, heat, malaria, lack of water, and, in the past, with slavers.

An attempt was made to open up land at Mlali, some twelve miles southwest of Morogoro, where an irrigation project was

constructed. Although many streams flow from the mountains, irrigation is not a traditional feature of the economy, and the Mlali plan was a new experiment for the Luguru. It was hoped that the plan would prove to be attractive enough to tempt the Luguru from the hills; to sweeten the bait no rent was charged for the use of the land during the first year of occupancy and only a nominal rent subsequently. The new project was a considerable success, so far as crop yield was concerned, but initially neither the operation of the scheme nor the utility of irrigation was fully comprehended by the Luguru. The scheme was not popular at first. Slowly, however, the project caught on. Land was first taken up by residents from Morogoro, who grew food and cash crops on their allotment, and later people from Mgeta entered the area, still retaining their home in the highlands and using the Mlali plots to supplement their other holdings.

Even before ULUS got under way, terracing had been carried on in the Mgeta area for some years. The land in this area is especially steep, and some terraces were only a single row wide—little wider than the width of the hoe. However, the Mgeta people approved the results of their terracing and in general were sympathetic with the broader ULUS. Their favorable attitude towards terracing limited the extent of dissatisfaction which arose later.

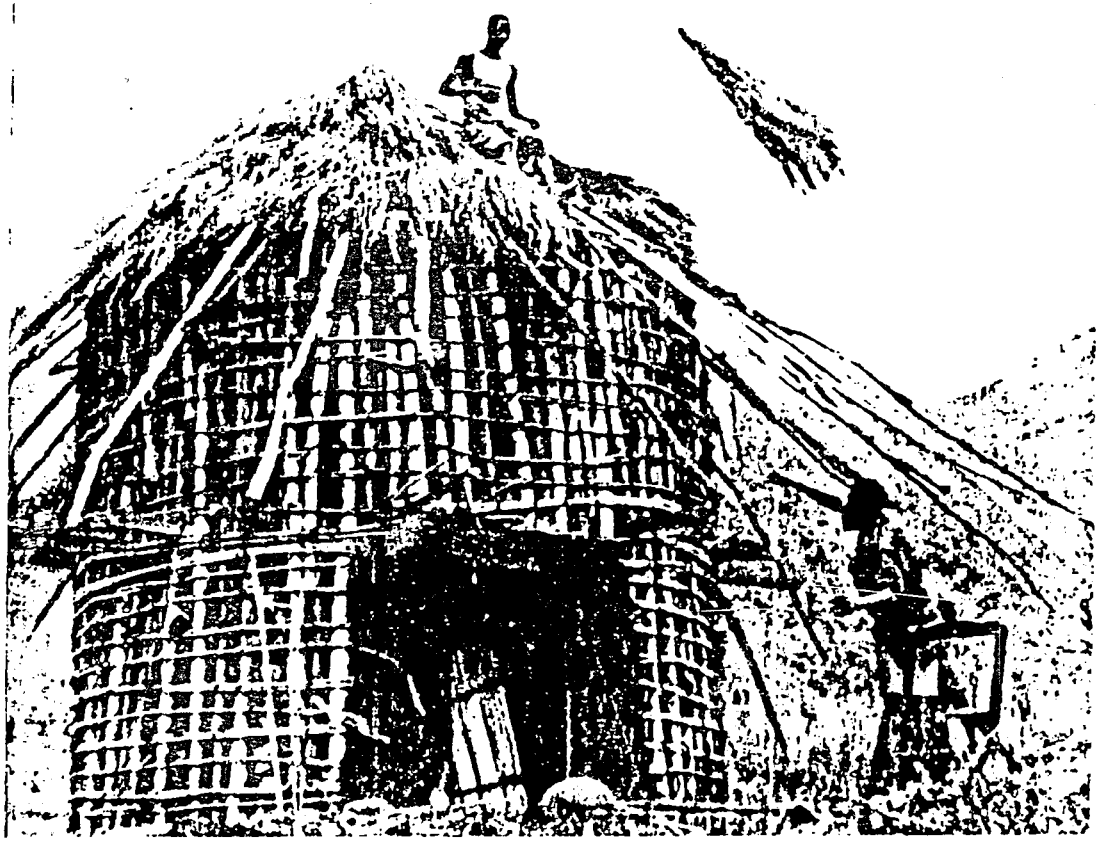
The official terracing program was introduced initially in but a few select areas; it began in Matombo in 1950, was extended to Mkuyuni in 1952, and to other areas later. By the end of 1952 little progress had been made, considering the ambitious nature of the plan to build bench terraces throughout the Uluguru Mountains. A new executive officer appraised the job ahead with some candor, saying that at the present rate of progress some 200 years would be required to complete the job, and funds would run out in four years.

In the earlier days the Luguru had not been attracted by ULUS and tended to be suspicious of land reform. There had been some violence, including a few instances where houses had been burned in recrimination against the proposals of terraces, but in general the scheme was tolerated, if not welcomed. The attempt to enlist the support of the clan leaders had limited success, but Kingalu, the former Sultan of Northern Uluguru, was persuaded to support ter-

racing. Unfortunately, the old chief died shortly after committing himself to the project, which to some Luguru was a bad omen.

As it happened, the death of Kingalu set in motion a series of events that directly affected the Uluguru Scheme. Kingalu was succeeded by his nephew, the son of his sister, and this new Kingalu, the thirteenth in line, at once claimed the title of Sultan then held by Sabu bin Sabu. He complained that he was addressed locally as Ramazan s/o Saidi and asked the District Office to recognize his title; he signed the letter Sultani Kingalu *mwana* Kinoge. In the various cabals and disturbances that followed, it turned out that Kingalu was a figurehead, the tool of his ambitious cousin and mentor, Ali Kingalu. Ali, son of the deceased Kingalu, would have inherited the title in a patrilineal society. The son could not be Kingalu or Sultan in his own right, but he reasoned that he might be able to wield power through his weak cousin. Ali was a nonentity so long as his father was alive, but with a new Kingalu in office he could gain influence for himself. He was an expert on the prerogatives and procedures of the office; in the expressive words of one informant, he knew "all of the proper series of grunts and coughs and sneezes when approaching Kingalu." Ali was ambitious and persuasive and in setting about on his new career as agent *provacateur* he used Kingalu for his own ends.

The letter from the new Kingalu, claiming the sultanship, caused some amusement in the District Office, where the claim was not considered seriously. The older Kingalu had been Sultan over a part of the Uluguru only; now the whole area had been united and centralized under a single Sultan, and it was not understood how Kingalu could rightly claim an office never held by his ancestor. Moreover, the office of Sultan was no longer considered to be hereditary (if it ever had been) nor was it identified with any particular traditional officeholder. The office had in fact been secularized, although it is fair to add that the traditional claimants to the office, those who had been supported when the policy of Indirect Rule was in full sway and encouraged to assert their claims, were not consulted when the newer policy was adopted. After receiving the letter, the District Commissioner visited Kingalu, explaining the current status of the sultanship and in the course of the visit discovered the nature of the relationship between Kingalu and cousin Ali.



Building Two-Story House in Uluguru Mountains

Forest Preserved as Sacred Grove

Terraces, Showing Landslide

Mbago Showing His Country: Mgeta Area

structing
Terraces:
Uluguru
ountains

In December, 1952, Mr. R. H. Gower became District Commissioner of Morogoro, and he at once developed a program of education to explain the scheme more fully to the Luguru, hoping to secure their co-operation. Adult schools were established to educate the peasant farmers on their stake in improving the land, but to a large extent the Luguru remained lethargic, supporting terracing grudgingly with their backs but not with their hearts. In expanding the program, the Government also employed additional African agricultural instructors, who were to supervise the construction of terraces and explain soil conservation to the peasants. Twenty-four agricultural instructors had been employed in 1950; in 1954 the number was increased to sixty. The standard of competence of the instructors varied considerably; one had been trained at Makerere College and for a period in the United States, but this case was exceptional and many of the instructors were poorly trained. The annual budget for the sixty agricultural instructors was only £2329, making the average annual wage of an instructor less than £40 ($112).

Some of the instructors, conscious of their new authority, were not always courteous in making suggestions or giving reprimands. They were, in fact, more than instructors; they were also agents of Native Authority and had some power to enforce the rules on terracing and soil conservation. They could grant permission to burn trash and could also report violations of rules for prosecution in the courts. It was frequently charged that the instructors took bribes and were corruptible, but in all there were only two or three actual convictions. Some who were closely associated with the Scheme thought that bribery itself was not common but that the Luguru resented being treated as schoolboys by these insolent outlanders. The instructors earned for themselves the unhappy name of "the army of black locusts."

Funds and time were running low, and to maximize the remaining resources ULUS abandoned its concentration on small areas and embarked on a more extensive program. Goals were set up in terms of running yards, with the hope that every Luguru household would bench-terrace annually some 300 running yards (one-eighth of an acre).

Table 14 reveals that the total number of running yards of ter-

races increased seven-fold in 1954 above the 1953 figures and that the rate was being maintained in the first two months of 1955. In the Mkuyuni area, however, the projected rate for 1955 was almost double that achieved in 1954; this increase reflected the aggresive leadership of the subchief, Abdallah Selemani. Communal terracing was

TABLE 14. *Terracing completed 1953–1955*
In units of running yards

	1953	1954	Jan.–Feb. 1955	Projected rate for year 1955
Matombo	399,284	7,444,800	685,500	4,113,000
Bwakira Juu	(Included with Matombo above)	1,073,240	222,100	1,332,600
Mkuyuni	427,615	3,403,229	1,033,524	6,201,144
Melela & Kingolwira	937,450	1,129,229	290,470	1,742,820
Mgeta	(248 acres)	(45 acres)	—	—
	1,764,349 *	13,050,498 †	2,231,594	13,389,565

* About 12 sq. miles.
† About 85 sq. miles.

introduced in Mkuyuni, and Abdallah Selemani proposed that the normal stint per household be increased to 600 yards per year. Instructors were said to have used threats to achieve spectacular records, and in some cases the figures gave a misleading picture of what was constructively accomplished. Farmers might select poor land for their terracing stint simply to comply with instructions, with the result that there was no visible return for the labor. The results of terracing even the better land were frequently disappointing. If sterile subsoil was added in the process of terracing, the land might be even less fertile and less productive than before. It was not easy to convince the Luguru that bench-terracing was a "good thing" when it resulted in smaller crops.

On the surface the plan was going ahead with great force, and there were not many overt warnings of trouble before the terracing riots broke out in the summer of 1955. The proposals put forward by officers and instructors were obeyed, and the Luguru apparently did not differentiate between mere exhortation to work and legal

regulations which they were expected to obey. They went doggedly ahead, doing what they were told, and becoming increasingly resentful. The sullen, angry discontent that became obvious during and after the riots was not expressed openly in council meetings.

It was said earlier in 1955 that the plan was "catching on," that the farmers were now seeing the value of soil conservation, and that the scheme had revitalized political consciousness. Whereas council meetings were formerly concerned with requesting new services without levying taxes to pay for them, they now discussed problems connected with the Scheme, such as the selection of the next area to be terraced.

However, all was not tranquil under the surface, and government in the rural areas was being called on to carry a heavy burden. There were reports of widespread bribery of head men and instructors to secure exemptions from terracing or to secure permission to burn trash. The bribery irritated both the honest and the dishonest, the latter being indignant when brought into court on charges for which a bribe had supposedly made them immune. Nor were the tools adequate. The hoe was unsatisfactory for terracing, for it tended to nibble into the supporting terrace walls and encourage erosion. The spade had not been used traditionally, and if used would require the addition of a foot plate (or the digger would have to wear shoes). Manure for increasing the fertility of the land was not available.

The riots

There was widespread resistance to terracing, and at this point two groups, having somewhat different purposes, entered the scene. One group was the Tanganyika African National Union (TANU), who were enrolling members by organizing the discontented and championing their grievances. The other group was the supporters of Kingalu, who hoped to make him Sultan. Although TANU took no official stand on the merits of the Uluguru Land Usage Scheme or the legitimacy of the grievances, its organizers were at the time actively enrolling members and collecting funds in the Luguru area. The appeal was made that once TANU was in power terracing

would come to an end, litigation for members would be handled free, and the ease of the old life would return. There is evidence that the Luguru killed in the Matombo riot was an organizer for TANU.

The followers of Kingalu offered a sentimental, nostalgic, mystical, and patriotic appeal for support. Kingalu was the symbol of the authority that prevailed in the old days before the arrival of the European, and with him in power there was the promise of more rain and better crops. The appeal for a restoration of temporal authority was made on somewhat shaky grounds, but in any event a former Kingalu had once been the Sultan. The fact that the former Kingalu had been Sultan over but a part of the area may have been more significant to the District Office than to Kingalu's followers. Why, it could be asked, was Kingalu not in power? The Tanganyika Government had adopted the policy of building on "tribal institutions which have been handed down to them through the centuries," and this policy had not been revoked. Although it does not take long in African politics to develop hereditary claims to an office, Kingalu was not a first-generation chief trying to establish a dynasty.

In the subsequent propaganda, an attempt was made by the insurgents to discredit Sultan Sabu. He was slandered with the accusation that he had enriched himself by supporting ULUS. The Government, the rumor went, paid a high price for his support, and Sabu in turn had bribed the subchiefs and headmen to support the plan. Another rumor had it that Sabu was frightened of Kingalu and paid him up to half his salary to keep Kingalu from claiming the office. The discontent with terracing became a vehicle of protest against Native Authority. It expressed itself in a demand for a return of old customs and old leaders. The discontent was organized and given direction by Ali Kingalu, who operated from his staff headquarters high in the Uluguru Mountains at Kinole, using runners to bring him information and to take messages to his subordinates.

From the end of June, 1955, events moved rapidly toward the climax of the riots. The Luguru began to tell the field officers that they were fed up with compulsory terracing. The barazas became menacing, and in some cases native law and custom was violated

when people appeared at open meetings with machetes. A clamorous baraza held at Mkuyani in June was attended by several hundred people instead of the usual thirty or forty. The general tenor of the complaints was that the people wanted to stop terracing and to get rid of their subchief, Abdallah Selemani.

On July 1 there was another meeting at Mkuyuni, and in what appeared to be an organized demonstration more than 1500 Luguru rose to their feet and brandished sticks. When the District Commissioner had finished speaking, Ali Kingalu gave a signal, and the crowd began to shout *hatutaki matuta* (we do not want terraces). People stood up, shouting wildly and waving sticks.

The bulk of the crowd dispersed after a promise of a further meeting, but some remained, running around excitedly. After the meeting an agricultural instructor was found to have been beaten up. He was lying in an Indian shop with bruises on his legs and face and suffering from shock. As the officials left Mkuyuni, three more agricultural instructors were stoned near the market place.

Further disturbances occurred subsequently. On the 4th July, the Sultan held a meeting at the court house at Mkuyuni, and another menacing demonstration followed. The leaders of the disturbances were given official status, at least in their own eyes, by virtue of the fact that they acted as spokesmen for the complaints. When the Sultan asked the meeting to name someone from the crowd with whom he could discuss their problems, the following four men stepped forward at once: Mohamed Mwinchuma, Mohamed Senei, the son of a Zanzibar sheik who had migrated to Kinole; Mohamed Hussein, Ali's chief lieutenant, who had once supported ULUS and busied himself in organizing terracing parties; and Ali Kingalu. The last three of those named above were later convicted of causing disturbances and imprisoned.

On July 5th, a meeting was called at Matombo, which was intended to be the beginning of a series of bush schools, but several hundred people appeared at the meeting armed with knives and sticks. At this point the District Commissioner decided to confer with Government officials at Dar es Salaam about future policy. It was decided in the capital that further meetings should be held in an attempt to reach an understanding on the grievances that had been

expressed, but there were recognized risks in holding open barazas and as a precautionary measure two platoons of mobile police were dispatched to Morogoro to keep order.

Negotiations were also entered into directly with the leaders of the agitation. After returning from Dar es Salaam the District Commissioner together with the Sultan and Deputy Sultan met with four of Kingalu's agents from Mkuyuni, and the Sultan had additional discussions with a deputation from Matombo. The official position was explained: abuses in the program would be corrected, but terracing must continue.

Two important barazas were scheduled for July 13th, to explain Government's policy; one was to be held at Mkuyuni in the morning and the other at Matombo in the afternoon. Some 2,500 persons attended the Mkuyuni meeting and listened to a speech in Swahili by the District Commissioner, who talked for some three-quarters of an hour. At the end of the baraza no one moved. The District Commissioner then spoke briefly with Ali Kingalu, who told the people to disperse. They dispersed straight away, with no unruliness.

A somewhat larger crowd, estimated at some 4,000, gathered at Matombo for the afternoon meeting, and the District Commissioner repeated the substance of the talk given earlier at Mkuyuni. He told the crowd that the police were present to ensure the maintenance of order inasmuch as the people themselves had come armed on previous occasions. The Government would not be intimidated by force. There were several interruptions initially, but the crowd remained quiet after being told to do so. The Uluguru Scheme must continue for the benefit of the people themselves, the District Commissioner said. The scheme was not responsible for the lack of rain, which had affected unterraced land as well as terraced land. The Government had heard reports of widespread bribery in connection with burning, but he was sure that a system could be developed whereby excessive trash could be burned without securing permission. Further discussion would take place on how terracing difficulties might be resolved, but hooliganism must stop. There were genuine grievances which demanded attention, he said, and officials planned to tour the area village by village and discuss these grievances on the spot. If disturbances continued, however, the district

would be declared a disturbed area, with a police force stationed there at the expense of the people. He also cautioned against subscribing money without getting a receipt. At the close of the talk, the people were told to go home and await further discussions in the villages.

Very few people moved. The District Commissioner then asked two insurgent leaders from Matombo, Shabani Fukio and Abdallah Mgeza, to tell the people to go home. Shabani Fukio was shouted down when he attempted to use the microphone, and the people asked him derisively when he had learned to use the radio. By now everyone was standing up, and the shouting became louder. "We will not dig; we will not terrace. Give us back our old ways," they chanted in Swahili.

Some of the crowd then turned on the Sultan who had been sitting at the side of the road during the baraza. They taunted him, saying that he had "signed the money away." "What sort of a chief are you?" they asked, and made threatening gestures.

The crowd became angrier. A fight broke out near the Native Authority Land Rover when someone attempted to get the crowd to disperse. The Sultan continued to be abused and threatened. The District Commissioner and the Superintendent of Police conferred and agreed that the situation was getting out of hand. They decided to call attention, legally, to the disorder by reading the Riot Act, so the District Commissioner stood high on the grass verge while he and others raised their hands above their heads in an attempt to draw attention to themselves and to call for silence. When a measure of silence had been secured, at least in the immediate vicinity, the District Commissioner spoke out the fatal words that if the people did not themselves disperse quickly and quietly, they would be dispersed by force. There was no reaction.

The first concern then was to protect the Sultan from possible harm. He was hustled inside the Land Rover, with the District Commissioner standing guard by the side window to protect him. Neither the District Commissioner nor the Deputy Sultan, who was standing nearby, was molested, the attack at this time being directed against the Sultan only. A group pressed in on the Land Rover in a fresh attack and succeeded in tearing the Sultan's clothes but not in removing him from the car.

The position of the Sultan was relieved when the police threw two smoke grenades, one falling in front and the other in the rear of the Land Rover; the crowd scattered, and the Sultan was driven off to safety. Once the Sultan was gone, the crowd turned its anger against the police, who were showered with clods and stones. One of the agitators in the crowd said that the people would not go home unless they were told that there would be no more terracing. Unluckily for him, he was accidentally struck on the head with a rock thrown by one of his own followers.

The police party attempted to protect itself by making a short baton charge to the edge of the road, but when the crowd did not disperse they were completely surrounded. The police retreated to their original post, where they were protected on three sides by houses, and then attempted to disperse the crowd by throwing their remaining smoke grenades and firing off the smoke shells. This was largely ineffective, for the rioters could avoid the area where the grenades fell and the smoke shells had to be fired at too sharp an angle to be useful at close range. During the siege, the police were pelted with rocks, and one third of them were casualties. Superintendent Barkley of the mobile police was struck in the face by a stick and several times knocked to the ground, and Superintendent Elkington received a concussion when a rock cracked his nose.

One of the ringleaders, a John Mahenge, was very excited. He jumped up and down, waving his arms, throwing stones, and encouraging others to take a bolder course of action. Superintendent Barkley, who was about twenty yards distant, shouted back to Mahenge and warned him with gestures that he would shoot if he didn't go away. Barkley was close enough to be heard and his gestures were unmistakable. There was no tear smoke between them.

Mahenge responded by throwing another stone. Barkley then took a rifle from one of the policemen, raised it in the aiming position, and pointed it at Mahenge. Nothing happened. The rifle was then lowered, Barkley made another gesture for Mahenge to leave, and Mahenge responded by throwing another stone. Barkley raised the rifle to the aiming position for a second time, and received a shower of stones. The rifle was lowered, and Barkley again warned Mahenge with word and gesture; Mahenge continued his belligerent behavior. Now Barkley loaded the breech, raised the rifle for the

third time, aimed at Mahenge's left knee, and pulled the trigger. As the rifle was fired Mahenge bent down to scoop up more stones, and the bullet severed an artery as it struck him in the groin. He was taken to the Matombo dispensary along with other casualties but died on the way.

The atmosphere was somewhat less tense after the shooting, but it was still menacing, and the crowd milled about for more than two hours before leaving. The police and the officials from Morogoro spent the night in Matombo.

The aftermath

Following the riots, ribbons of smoke rose defiantly all over the Uluguru Mountains. Rules against burning were no longer enforceable, and the peasants now openly flaunted authority by firing the hills. District officers who addressed public meetings found the people sullen and unco-operative and firm against terracing, and at some scheduled meetings no one would show up. The Sultan kept close to Morogoro for fear of personal injury if he ventured too far into enemy territory. The terracing program was modified, but even with modification it was no longer feasible and was all but abandoned. None of the July rioters was arrested initially. This seems to have been the policy laid down by the Central Government in Dar es Salaam, and police officers also claimed that it was difficult to get the evidence required for an arrest. The rioters pressed their advantage and carried on a vigorous campaign to remove several subchiefs and headmen identified with terracing —and in particular Abdallah Selemani, the subchief at Mkuyuni, and the headman at Kinole. They were successful in these two cases. The subchief at Mkuyuni, who had had ten years' experience and was considered one of the best subchiefs in the district, was suspended. As a supporter of terracing, he now commanded no influence among the people in his area and was even in some physical danger if he continued in office.

The attempt to make Kingalu the Sultan of Uluguru met with less success, but in the meantime the reputation of Sultan Sabu was tarnished and he became inactive politically. His work was confined

to his office, inasmuch as visits to the rural areas of the district might be uncomfortably dangerous. If a new Sultan had been chosen, it is unlikely that Kingalu would have been acceptable to the Government; he is ignorant, superstitious, illiterate, and without knowledge of or experience in modern administration.

Within Government circles, there had been no unanimity on the utility of bench-terraces, and some officials were satisfied to modify the somewhat rigid plan. Under the new regulations, terracing was but one of the several permitted methods of soil conservation, the others including ridge planting, step terracing, trash bunds, hedge bunds, and rock bunds. Greater freedom was allowed in burning trash without first securing permission. Communications in the mountains being what they were, it was estimated that it would take the Government many months to explain the modified plan.

The Government's hope that the new regulations would be accepted were quickly dashed, for the Luguru wanted to have done with terracing once and for all. The usefulness of the barazas for putting forward the Government's views was thwarted by Kingalu's men, who were active in sowing discontent and spreading their own views. The barazas called to explain the new terracing plans often skirted the edge of open violence. Many came to the meetings armed with pangas and sticks. The crowds were noisy and menacing and threatened the African agricultural instructors who attempted to explain the new rules. "Down with terracing! Down with Sultan Sabu!" the people cried. Some meetings were organized in advance and tended to feed the discontent rather than restore confidence.

For a time, Kingalu and his group had the Government on the run: no one had been punished for the riots; the Government had yielded on terracing; Sultan Sabu and Subchief Abdallah Selemani, who were the symbols of terracing, were now ineffective. The Government, apparently, could be made to yield under pressure and the threat of violence.

In September, 1955, a new crisis occurred. On the occasion of this outbreak of violence, however, there were several arrests, and in the end, after trials and appeals, four of the ringleaders were sentenced: the three already mentioned, Ali Kingalu, Mohamed Senei, and Mohamed Hussein, and a fourth man by the name of Mwenemvua

Kingalu. This new disturbance was not directly connected with the dispute over terracing, but the fact that it occurred at all was due to the unsettled conditions of the area and the ability of Ali Kingalu to command the mob.

This latest incident occurred during a session of the local court in Mkuyuni, which at the time was hearing a case concerning the illegal cutting of *mvule* trees. While the court was in session, a local man by the name of Ali Kambi interrupted the proceedings and accused the headman, who was sitting in the court, of having illegally arrested ten men who had refused to act as porters. The court, with open walls, was easily approachable and so subject to interruptions and disturbances from the outside.

Knowing that Ali Kambi would charge the headman in open court, Ali Kingalu and about 700 followers, armed with sticks, stones, and knives, entered the court or surrounded it on the outside. When Kambi made his accusation, Kingalu's crowd broke into an uproar for some fifteen minutes, then stopped suddenly when Ali Kingalu clapped his hands. The court was intimidated; it dropped the *mvule* case, served a summons, and started straight away to try the headman. The tables were turned, with the headman-judge now being the defendant. One of the old men on the court who issued the summons later said that he had no alternative. If they had issued instructions to arrest Ali Kingalu, all members of the court might have been killed. Many armed men were present, and he had been badly frightened.

After these latest disturbances, part of the District was declared a disturbed area and police were brought in to maintain order. A special tax of three shillings a head was levied to pay the cost of maintaining the mobile police. About 21,000 Luguru were eligible to pay the tax, of whom about two-thirds paid up; the Government is not attempting to collect the remainder. Several arrests were also made. Trials, convictions, and appeals followed, and in the end Ali Kingalu and three others were given sentences of up to a year in prison, following which the four were rusticated, on the Government's orders, to Biharamulo, a dry tsetse-infested area in northwestern Tanganyika, for another year. (They are back in the Morogoro District, but have been up to no mischief since their return. Ali Kingalu is busy encouraging his neighbors to build a road to Kinole. Bicycles

have been purchased in anticipation of the road, and some in Kinole have been practicing to ride a bicycle by coasting down the side of a hill.)

In the subsequent years, the Government has attempted to restore the confidence of the Luguru through discussions, signs of good faith, a reconsideration of the terracing program, and above all by encouraging the growth of cash crops. There are also prospects that new land will be opened on the plains, possibly under irrigation, which in time may relieve the pressure of the population in the hills. The emphasis has been changed from regulations and restrictions to helpfulness and encouragement. The price paid for the restoration of confidence has, in effect, been the scuttling of the Uluguru Scheme, particularly that phase concerned with terracing and soil conservation. The agricultural techniques currently followed in the Uluguru Mountains are, even now, no great advancement over traditional methods; the developments here are not comparable with those that have been made in political institutions. In short, ULUS is yet another of the several large-scale plans designed to improve the living standards of Africans that have been disappointing in the results achieved.

Causes of the riots

We may now ask the question, Why did the riots occur? In answering the question we will consider the part played by the Luguru, the technicians, and the administrators. There were internal political conflicts among the Luguru which made it possible for tensions to develop, and one might be justified in saying that the riots would not have occurred had it not been for the ambitions of Ali Kingalu. Ali took advantage of the discontent over terracing and organized it for his own particular ends. Although Ali was perhaps the major force in bringing the discontent to a head, there were also other factors among the Luguru which tended to undermine the program.

The political institutions were deficient in that they provided no acceptable method for expressing hostility and discontent; emotions developed with no opportunity for expressing them openly. The

various councils and the hierarchy of officialdom, including headmen, subchiefs, and chiefs, did not provide an effective conduit for bringing complaints to the surface. The district officials were isolated from direct contact with the peasants. When in the field, they were accompanied by subchiefs, headmen, or agricultural instructors, and the Luguru were reluctant to present their complaint, especially if reprisals might follow. It was prudent to remain silent.

The discipline that it was thought necessary to invoke was exercised by Native Authority, which had not developed into a sufficiently competent or efficient organization to assume this burden. Governmental action involves a process of interrelated functional roles, and the people who exercised the authority in this case were not expertly trained, knowing the precise requirements of the role they were to perform. In some cases, also, an attempt was made to divert the process by granting exceptions for favors received or by using the influence of the roles they assumed for personal gain or personal spite. Perhaps in the long run the Native Authority could have carried out the job if they had received greater support from the people and if the Luguru could have been persuaded to accept the reforms. But these two factors were missing, and the crisis revealed how tenuous the political process can be when it is required to carry out functions that are different from and contrary to the culture of the people.

The Luguru entered the Scheme reluctantly, almost against their will, and they did not demand the reform. They were on the whole apathetic toward the program, and there was no clear economic improvement to be seen, even after terracing. Moreover, at an earlier period, the conservation of soil had been discussed in a manner that frightened the Luguru, such as the talk of forced migration. Land conservation became associated with the loss of their land. The Luguru wanted to retain their old customs, not embark on a program of reform: *Tunataka desturi ya zamani*, they said, "We want the customs of old."

Lectures were given, slides were shown, and there were demonstrations of how to build terraces, but these various stimuli were not sufficient to persuade the Luguru to accept terracing. Some thought that demonstration areas, showing hillsides terraced in the approved fashion and growing abundant crops, would have pro-

vided the necessary enticing carrot, but these areas were not built, at least not for public view. The terraces were often disappointing, for the soil in some cases was so thin and worn that the finished terrace was no more productive than it had been before.

The opposition that developed may have been more deep-seated than the controversy over terracing itself. The use of land was now to a degree controlled and regulated by outsiders, those who were not part of the traditional Luguru social system. Everything was changing, and even Native Authority was a foreign way of governing. The loss of fertility of the soil could mean that new ways were not good ways. Life was poorer than it had been, and another step into the unknown future would mean yet another break with the past. Both nostalgia and patriotism were on the side of the old customs, and in the crisis the taunts were directed at foreign Africans, who had authority over them and who represented a threat to their way of life.

The organized reaction to terracing assumed a form which was not approved, in the Western sense of the term, however effective it may have been for the rioters and the plotters. In examining the cause of the riots, a subplot develops, another thread to the story of the competition for authority and influence among the Luguru. It is in a way coincidental that the claims and challenges of Kingalu should have been associated with the humdrum process of terracing the hillsides. Neither process was essentially related to the other. However, in political conflict one often chooses for an issue some vulnerable aspect of the opponent's position, the most sensitive political subject, the issue most likely to enhance the support of one's adherents. The issue selected for the contest with the Government might have been concerned with roads, schools, sisal growers, bridewealth, or a number of other topics, had there been a similar dissatisfaction with the policy being followed and an equal chance of success. The issue of terracing, however, had the singular advantage of affecting a large number of people where dissatisfaction already existed, and the dissatisfaction needed only to be mobilized.

Some technical errors also contributed to the ultimate failure of the scheme, perhaps the greatest being the incomplete nature of the initial plans. There was never a clear and agreed plan of what goals were to be accomplished: higher productivity, or conservation of

soil, or preservation of watersheds, or the opening up of new land on the plains to which the Luguru might be persuaded to move. The methods followed were equally equivocal. It was unrealistic to bench-terrace all of the Uluguru Mountains, which meant in fact to level off some 400 square miles of arable mountain land. In the short time available, it might have been more rewarding to have gone more slowly and thoroughly, and persuaded the Luguru to change their methods. The money came suddenly, an expected piece of manna in the desert, and there had been little experimental work on how to spend the grant. The proponents hoped that more funds would follow once the plan got under way, but very little was in fact added to the original sum. The scheme began, accordingly, with money in hand but with no clear goal.

The major emphasis was on bench-terracing, which brought in its wake hard work, onerous rules and regulations, strict control by an army of imported instructors, and few practical results. The terracing of land and the planting of trees were part of a broader plan of water conservation, designed to prevent the silting of streams and their transformation from permanent to periodic rivers. This goal seems to have been lost sight of in the development of the Scheme; no continuous measurements were made showing the possible effect of terracing on the flow of rivers, and ULUS officials in the latter years were unaware that one reason for adopting the scheme initially was to preserve the fresh water streams in the coastal area.

Although the technicians believed that the Uluguru Mountains were carrying too heavy a population, relatively little was done to promote migration. The irrigation scheme at Mlali was popular, once the project was explained and its benefits were obvious and could be seen, but there was no attempt to develop the water potential on a large scale. In the years since the riots, experiments have been conducted by the Tanganyika Agricultural Corporation on the potential development of the flat, relatively fertile, and thinly populated land to the south and southwest of the Luguru massif, and this may be the area where the surplus population will eventually go. Under ULUS, however, few provisions were made to make migration easy; or to assist in the pattern of migration followed by the Luguru of keeping a foot in both camps until the new area has proved to be satisfactory. A somewhat tougher line was followed.

As early as 1944, there was discussion of the need for compelling the Luguru to move to the plains, and the Luguru developed suspicions which were never completely allayed.

There has been a slight improvement in the economic condition of the Luguru in recent years, due largely to the sale of coffee. Coffee plantations were developed in the area by the Germans half a century earlier, but the crop has been little grown by the Luguru until recently. In 1955 the growth of coffee by the Luguru was encouraged by a field officer, and it has proved to be a popular crop.

Another technical shortcoming was the failure to test the utility of bench-terraces in the Uluguru Mountains, although some technicians claimed, or claim, that no further experimentation was needed. When the policy of bench-terracing was adopted, it was said to be a proved method which did not require further experimentation, and the failure of the land to produce after terracing was due to the inherent poverty of the soil. But the essential rightness of the method was of little comfort to the administrator who, under such adverse conditions, had to persuade the Luguru of the advantages of terracing, nor was it of comfort to the Luguru, who found terracing unprofitable and unproductive. In the 1956 annual report of ULUS, written after the riots, the lack of experimentation was criticized. "Basic experiments which should have preceded the scheme have been started," it stated, but the experiments were not encouraging, and it was found that "rice land yields are frequently better on untreated land than on terraces."

Another factor, perhaps inherent in the nature of technical proposals, was the considerable gap between the abstract ideal of the scientists and the concrete reality of African life. The technical experts, properly concerned with the preservation of natural resources, couched their proposals in precise abstractions. The solutions for such pathological conditions as the erosion of the soil or the destruction of forests tended to be stated in dogmatic terms, the technicians having in mind a standard of conservation that was not part of African tradition. More attention was paid to the desirable ends than to their implementation or to the impact on African society of the new policy. In the early days of the Uluguru Scheme, a field officer, with considerable acumen, pointed out that "while it may be possible to improve the methods of cultivation in six and a

Terraced Land, Uluguru Mountains

Smoke in the Hills

half years, it is impossible to alter the way of life in that time." The technical officers often advocated policy, supported by scientific knowledge and the rules and the prestige of the Government, without realizing the extent to which a change in the pattern of African life was involved in the policy they proposed.

There were also factors in the administration of the project which made success difficult, for the administrators were in fact caught in the center of a sharp conflict: on the one hand there was an African society somewhat suspicious of change, reluctant to adopt new methods, and exploitable by the leaders of discontent and protest; on the other hand, there was the attitude of the Western world, supporting and demanding a fuller, richer life for Africans. And there were also the difficult, perhaps impossible, goals of agrarian reforms proposed by the technicians, which the administrators must implement.

The senior staff assigned to administer ULUS was small, and so too was the budget for the whole project. The immediate staff consisted of an executive officer and three to four field officers. They, with the assistance of up to sixty African instructors, supervised the program affecting some 100,000 Africans. The money available for the Scheme averaged approximately £5,000 a year. In an undertaking of this magnitude it was necessary to delegate considerable authority to the instructors and to officials in Native Authority. Nevertheless, the senior staff spent much time in the field, often on foot in the rough mountain terrain. Comment has already been made that legitimate complaints were not expressed to the senior staff because they were often accompanied by some minor official and the complainant feared reprisals. This criticism is perhaps applicable to the entire political system, of which the administration of ULUS is but an example. The conciliar system was created, in part, to provide a method by which grievances could be expressed; the extent that the councils did not perform this function is a measure of their failure.

It has also been suggested that the administrative organization of ULUS was defective. ULUS was first placed in the office of the Provincial Commissioner, but at those Olympic heights it was found to be too remote from the people and it was then placed in the District Office. An executive officer was put in charge of the project,

and field officers worked under his direction, although the District Commissioner had final responsibility. District officers who were not associated with the project have commented that this arrangement left a good deal to be desired; the District Commissioner was responsible for his district, yet he did not have direct control over one of the most important projects there.

The administration of the Uluguru Scheme was also handicapped by staff turnover, which is endemic in District Offices throughout Tanganyika. It was unusual for an officer to be assigned to Morogoro for as long as three years and most assignments were for shorter periods. During the years of ULUS, there were four District Commissioners (two for short periods) in the Morogoro office, three executive officers assigned to the Uluguru scheme, and a number of field officers. No one person was associated with the project from its inception, and there was a consequent loss in accumulated experience which would make it easier to mould and change a policy and to recognize pitfalls and danger signals. This was also true in the Provincial Office. ULUS was also saddled with a mixed bag of agricultural instructors, holding temporary appointments; some were competent, but many were deficient in experience, schooling, and general effectiveness. So now the circle brings us back to the need for more schools and better training, for more taxes to support the schools, for more production to supply the taxes, and for better land to raise more crops.

In summary, one can say that it is not easy to identify any single factor that led to the riots and to the rejection of terracing on the part of the Luguru. Here was an example of cultural conflict, where the goals and methods of the dominant group were not accepted by those who were supposed to benefit from them. In retrospect, however, one can examine the areas where the conflict seemed to be most pronounced, although it would be imprudent to say flatly that the Scheme would have been successful had these conflicts been resolved differently or if they had never arisen. There were (and are) political tensions in the Luguru society that did not find expression through the devised political institutions. Basically, it appears, the Luguru did not want terracing, and they looked upon such innovations as a threat to their way of life. To a degree, of course, they were right in their estimate of the nature of the threat. The dis-

content might have found other methods of expression, or it may have lain dormant, but as it happened Ali Kingalu appeared at the propitious time to make the most of the dissatisfaction. There were also several technical weaknesses. The terracing plan was carried forward with a certain degree of inflexibility and too little experimentation, but additionally there was a dearth of essential scientific knowledge of the physical conditions of the area. Administratively, the senior staff was perhaps too small, and the junior staff too immature for a scheme of such magnitude, and administrative experience was lost through the high rate of turnover of senior personnel.

Appendix V

THE NATIVE AUTHORITY LAND USAGE (MOROGORO) RULES, 1951 *

(Rules made by the Uluguru Native Authority and approved by the Governor under section 16 of the Native Authority Ordinance, Cap. 72.)

1. These Rules may be cited as the Native Authority Land Usage (Morogoro) Rules 1951 and shall apply only to the Uluguru Chiefdom.
2. In these rules, "Native Authority" means the Sultan of Uluguru and includes any sub-chief who has been empowered by him to act under these rules.
3. The Native Authority prohibit the planting and cultivation of crops, the felling of trees, the lighting of fires and the grazing of cattle, goats or sheep in areas which shall be demarcated, which:
   (a) border upon a stream, spring or dry river bed;
   (b) are severely eroded;
   (c) are land from which the water run-off causes or threatens to cause soil erosion on land below it;
   (d) are on the advice of an Agricultural Officer or Veterinary Officer, unsuitable for cultivation or grazing purposes.
4. No inhabitant is permitted to cultivate land or fell trees or strip bark off the trees, in an area demarcated in accordance with Rule 3 unless he is permitted by the Native Authority to do so. If any trees are cut down they must be replaced by seed or seedlings.
5. Any person who is occupying land which has been demarcated in accordance with Rule 3 above shall cease to cultivate such land as from such date as may be ordered by the Native Authority provided that:
   (a) he has permission to continue to maintain and use of any trees which were planted by him upon that land prior to the 1st November, 1950;
   (b) he must replace any trees felled by him for his own use.

* NOTE: This is not the official translation but a translation by Mr. Fosbrooke, to whom only a Swahili copy was available.

6. Notwithstanding the provisions of Rule 5 any person mentioned therein may be permitted by the Native Authority to cultivate on such land for a period not exceeding 2 years so that the clearing of ground around young trees may be continued.
7. Any person who shall commence to cultivate on sloping ground must follow the instructions of the Native Authority issued after consultation with an Agricultural Officer, in order that the soil shall not be carried away by water.
8. The owner of any cultivated land which is in the opinion of Native Authority in consultation with an Agricultural Officer insufficiently protected against soil erosion, must obey such orders as the Native Authority shall issue.
9. For the purpose of Rules 7 and 8, above, the Native Authority after consultation with an Agricultural Officer has the power to make orders concerning—
   (a) the construction of bench or contour terraces;
   (b) the prohibition of the burning of crop residues, weeded grass, thicket or felled trees;
   (c) the construction of and maintenance of storm drains above the cultivated land.

   The Native Authority has power to make orders concerning the breadth and height of the terraces.
10. If on any land work is done in conformity with directions given by a Native Authority under these rules to prevent soil erosion, the owner of the land shall maintain the works in accordance with the directions of the Native Authority.
11. The Native Authority has the power to prohibit or restrict the grazing of cattle, sheep or goats in any area.
12. Any person who contravenes any of the provisions of these rules or any orders made under Rule 13 shall be guilty of an offence and shall be liable on conviction to a fine not exceeding 50/– or to imprisonment for a term of one month or fine and imprisonment. For the second or subsequent offences this may be increased to a fine not exceeding 100/– or to imprisonment with hard labour not exceeding three months.
13. In addition to the punishments stated in Rule 12, above, every Court has the power to inflict the following:
   (a) prohibit any person found guilty of an offence against these rules from cultivating the land in respect of which the offence was committed until such time as the Native Authority

shall be satisfied that the breach of the rule has been remedied;

(b) to order the culprit to uproot and if necessary, burn any crops, trees or plants planted by him in contravention of these rules;

(c) to order the culprit to plant such trees or plants as it may consider necessary on the land in respect of which the offence has been committed.

These are the rules of the Native Authority of Uluguru referred to in my certificate.

Date: 29th January, 1952

Sgd: Sabu bin Sabu
UTAWALA WA WENYE II
(Native Authority)

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INDIGENOUS METHODS

Berry, L. and J. Townshend. 1972. Soil conservation policies in the semi-arid regions of Tanzania: A historical perspective. Geografiska Annaler 54(9A, 3-4): 241-253.

SOIL CONSERVATION POLICIES IN THE SEMI-ARID REGIONS OF TANZANIA, A HISTORICAL PERSPECTIVE

BY LEN BERRY AND JANET TOWNSHEND

Both formerly of BRALUP, University of Dar es Salaam

ABSTRACT. The semi-arid regions of Tanzania have been plagued by problems of soil erosion, at least since 1900. This paper outlines the various approaches to these problems in the dry areas of the country in the period 1900—1970.

The causes of erosion given by the colonial administration are presented together with an examination of the agents of conservation.

Some of the more important conservation schemes and techniques are reviewed and the reasons for their comparative success or failure are discussed.

Introduction

Measurement of rates of erosion generally show the occurrence of much higher rates in steeply sloping areas. For example, Corbel (1964) shows mountain areas to have, on average, rates 10—20 times higher than the lowlands and figures presented by Fournier (1960), although disagreeing in many other points, show similar differences of erosion rates with relief. Perhaps in response to this, perhaps because of the more defined nature of the problem, or because of the attractiveness of the landscape, much more attention has generally been given in Tanzania to the problem of soil erosion in the mountains.

However, the semi-arid plateau areas of Tanzania have equally pressing problems. Erosion rates are high and replacement rates of soil are a good deal lower than in the upland areas. The effect of soil erosion on land and people is thus considerable. Solutions of the physical problems are more difficult in these areas because the use of land and the resultant erosion and deposition are intrinsically bound up with the cultural and social systems. Cattle and more cattle are an important part of social wealth and prestige to the farmer. For example as Rigby's recent work clearly shows, a considerable mobility in the face of drought or other land problems is a normal preservation device for the Wagogo (Rigby 1970). That is to say, if land is scarce or useless, the solution is to move and not to improve existing land. This is in strong contrast to the mountain areas where land is scarce and is a vital possession. Thus in the mountains an individual farmer is more likely to handle his land carefully.

Increasing population, both human and animal, serve to steadily intensify the problem of a diminishing resource base in the plains. Solutions demand a major reappraisal of the physical and human use of the area. While overgrazing is the predominant problem in some areas such as Arusha, Mbulu and parts of Singida, erosion on cultivated land is equally menacing.

The main areas considered in this review are Sukumaland, the old Central Province of Tanganyika, Masailand and Mbulu District (Fig. 1). The historical analysis is meant to serve as a background to the following three contemporary studies of erosion in these areas. It is meant also as an indication that few easy solutions can be expected.

Historical background

Soil erosion has been a problem to be faced in parts of Tanzania, at least since the beginning of this century. By 1930, soil erosion was a menace in a number of areas. Gillman writes:

"It (erosion) is, thus, most concentrated in the more densely settled regions of the semi-arid country in the tilt-block topography of the Great Rift with its comparatively loose and shallow and dominatingly granitic soils. Ugogo, Irangi, Unyaturu, Isanzu and S. E. Usukuma are the typical representatives of far advanced erosion. Surrounding this "core-land", marginal lands often extending from the severer climate expressed by thornbush into the slightly moister type indicated by *Brachystegia* dry savannah forest, carry areas of soil erosion, and these areas seem to grow in extent in proportion to the density of population, i.e., in proportion to the extent of artificially created "culture steppe". Northern Usukuma, Sonjea, parts of Ufipa and Uha are typical examples. Purely nomadic grazing, on the other hand, as e.g., in much of the Masai and Mangati country, where the scarcity of

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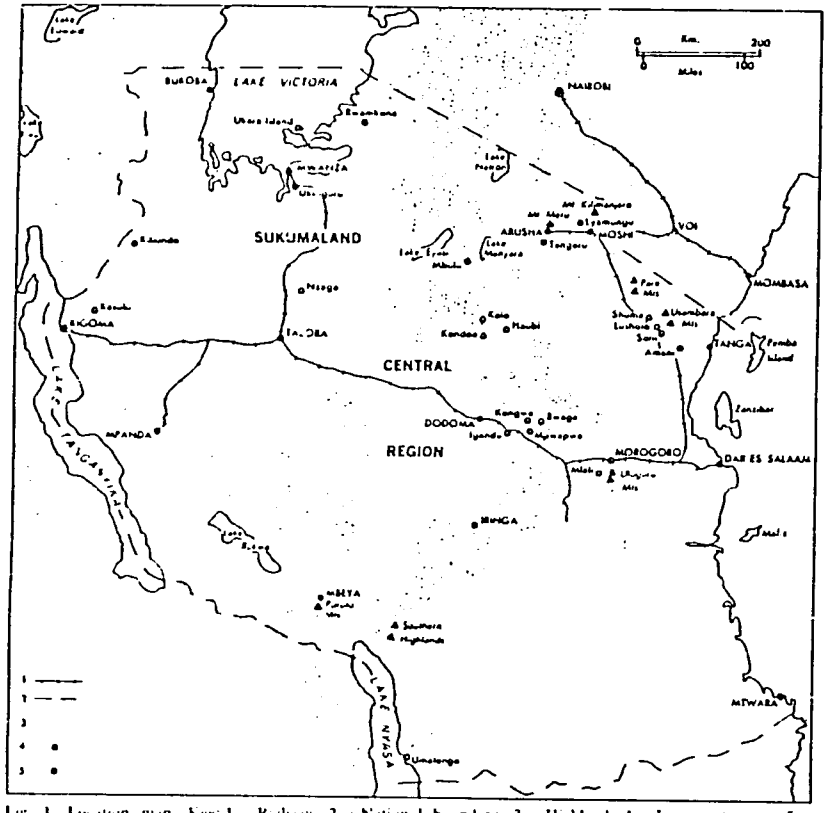

Fig. 1. Location map. Key: 1 = Railway. 2 = National boundary. 3 = Highland. 4 = Important town. 5 = Other place mentioned in text.

natural water supplies is the best safeguard against overstocking, is decidedly free from soil erosion, except in the vicinity of water holes where periodic concentration of cattle takes place" (Gillman 1930, p. 5).

Conservation methods were built into some local agricultural systems and must have been practiced over many generations but before 1930 there was little government concern with the problem (Hartley 1938, Stenhouse 1944, Thornton and Rounce 1936). In 1929, the situation changed when E. H. Harrison was appointed Director of Agriculture. One of his major interests was in soil erosion, which was then gaining prominence in international scientific circles and he was prepared to make soil conservation a priority of the Department. Further impetus was given by the severe and widespread droughts of 1929 which were followed by a season of exceptionally heavy rain in 1931.

A conference on soil erosion was held at Dodoma in 1929 and the meeting led to the establishment of an advisory committee on soil erosion. This committee met for the first time at Amani in 1931 and found it easy to quote many examples in presenting the problem to

the central administration (TNA 1). Two main problem areas were seen to exist; the "overcrowded" mountain areas (Temple 1971) and the "overstocked" pastoral areas in the plains. The need for conservation work was agreed on and a sub-committee was formed which was to advise different technical departments on the introduction of demonstration plots, the planting of improved browse plants in pastoral areas and the alienation of land for forest reserves. The committee saw the great problem of the plains as overstocking, but it saw serious difficulties in trying to reduce stock numbers. It was more practical to introduce water supplies and improved pasture, but this again would lead to larger herds, posing an even greater problem. In 1932 the committee emphasized the menace erosion was presenting to the new railway extension in Central Province and the excessive erosion being caused by burning in Northern Mbulu and overgrazing by the Masai in Ngorongoro.

During the 1930s a number of demonstration plots were set up in the mountain areas of Kilimanjaro, the Usambaras, the Pares and Mt. Meru. Harrison and other researchers wrote on the methods of conservation which could be used in these areas (Harrison 1935). The demonstration plots were used by the administrators to convince the "Native Authorities" that soil conservation was necessary to give better yields on steeper slopes and maintain the fertility of the soil. The Native Authority was a local government, usually comprising the chief of a tribe and his council. The Assistant District Commissioner would liase with this local government and through them impose the will of the Central Colonial Administration. The Native Authority was empowered to enact orders using their own ordinances.

Experiments were carried out at Agricultural Research stations throughout the country, to measure soil and water loss from land with different types of vegetation cover (Staples 1933, 1935, 1938), to measure yields of coffee and cotton on different types of land management (Annual Reports of the Research stations at Ukiriguru and Lyamungu) and to discover which pasture plants combined soil conservation properties with adequate nutrients for use in Central Province (French 1943). These experiments went on right into the mid 1950s—the major work being performed at Mpwapwa (van Rensburg 1955, 1958).

At a conference of technical officers at Mpwapwa in 1936, Staples said that "erosion in Central Province is rampant in its most acute form over large areas" (TNA 2). He believed that this was mainly due to wrong methods of cultivation and overstocking as stock rates were now over the carrying capacity in many areas.

By 1939 there were reports that the measures introduced by the Native Authorities of eight Districts (Moshi, Korogwe, Pare, Arusha, Mbulu, Iringa, Rungwe and Mbeya) covering all cultivation were being successful in conserving the soil. The measures were therefore being extended to other areas notably the Ulugurus (Harrison 1938*a*, 1938*b*, 1939 and TNA 3). The only disappointing areas were the pastoral lands such as Central Province and Sukumaland where no progress could be made until the Native Authorities appreciated the need for integrated pasture care, using rotation and a good distribution of watering places.

In the early 1940s there was a continued expansion of soil conservation, notably in Central Province where thousands of miles of contour banks were being constructed by local people under supervision of the Department of Agriculture Extension staff (TNA 4, TMA 1). A number of areas in Dodoma, Singida and Shinyanga Regions had been set aside for controlled grazing experiments and plans were in hand to combine this with depopulation, reduction of stock and resettlement schemes.

Despite all these efforts, progress was hampered for two reasons. Firstly there was a great shortage of trained technical staff, so that the efforts of the Department of Agriculture were necessarily concentrated in accessible areas. There were only about 50 fully trained Agricultural Officers and Assistants (Fuggles-Couchman 1964). Secondly the climate of the territory consistently hampered conservation because if the weather was dry there was no obvious advantage of soil conservation measures and if the rains were heavy the conservation works were often destroyed. The concentration then had to be on repairs rather than construction and people became discouraged. To try to deal with the first problem the colonial government established a soil conservation service at Tengeru in 1948

which was to train extension staff who would then go to all Districts to advise on the execution of schemes (ARA 1948). But the second problem was ever present and could not be dealt with until some conservation works had existed for many years and there was visible proof of improving yields and increased soil fertility.

Up to the early 1940s soil conservation had been a piecemeal affair (i.e., there was not organized policy for the whole country). There were very few areas where the majority of farmers were now soil conscious. The central administration saw that there was a need for integrated large-scale schemes in the worst effected parts of the country with central government funds to supplement the grants of the Native Treasuries and with more trained manpower to ensure smooth running. In 1944, when a favorable outcome of World War II appeared certain a comprehensive post-war development plan was drawn up to cover the period 1947—56. One and one-quarter million pounds out of a projected budget of 19 million was allocated to 8 agricultural schemes, covering 68,500 sq. miles and affecting two million people. (Fuggles-Couchman 1964). This was the period of the ground nut scheme, a disasterous attempt to utilize the semi-arid plateau which failed in part through a lack of understanding of climatic and soil conditions in the area (Wood 1950).

In Sukumaland and at Kolo in Kondoa, pilot areas were set aside for rotational grazing and resettlement schemes. These were the small beginnings of the two most important conservation schemes in the semi-arid area—the Sukumaland Development Scheme, 1946 (TNA 6) and the Kolo Rehabilitation Scheme, 1948 (ARA 1948). Two other major schemes were planned for the Ulugurus and the Usambaras and with seven smaller schemes soil conservation was thus extended to all parts of the country (TNA 7). All the big schemes had impressive lists of rules attached to them, governing such things as place of cultivation, extent of grazing and prohibitation of burning. People were convicted and fined if they contravened the rules.

This increase of effort did not continue. For many reasons, the people began to be discouraged and often became directly opposed to the conservation measures which had been introduced. Conservation became a political issue in the vicinity of major schemes and by 1954 many of the schemes were being forced to disband after civil disturbances had stopped any active conservation effort. The government were forced to stop enforcement of the conservation rules and by 1958 most of the schemes had fizzled out and people were busy pulling down many of the terraces and banks which had been so painstakingly constructed.

The colonial administration did not give up entirely. In one area they began rather belated plot experiments to discover plant behavior under different land management (Temple 1972) and detailed soil and water conservation and land use schemes were being worked out at Tengeru, Ukiriguru and Iringa (ARA 1950). In areas peripheral to the main schemes there was often an initial interest in organized conservation for example, Ukara Island Native Authority published its first conservation orders in 1958 (TNA 8). But in general, the colonial administrators were cautious and concentrated more on improving individual holdings and on more general catchment experiments (Temple 1971).

For some time after independence there was very little direct mention of soil conservation in the Ministry of Agriculture files. In fact, agricultural schemes incorporated conservation but not usually as the central theme. For example, the Ufipa Wheat Scheme, the Kitulo Sheep Scheme and the Turkish Tobacco Scheme in the Southern Highlands (TMA 2) and the Gulu and Rwamkona assisted settlement schemes of Sukumaland (TMA 3) have all combined soil conservation with the other aims of the projects. Although the extension staff of the Land Planning Units in the Ministry of Agriculture do offer assistance to people who desire to conserve their land, there has only been one big scheme incorporating land planning, conservation and settlement which was begun at Shume in the Usambaras in 1963 (TMA 4).

In general, soil erosion has not been seen as a problem to the development of Tanzanian agriculture in the 1960s although the senior soil scientist at the Ministry did point out the dangers of clearing land in Tanzania without planning conservation (Baker 1969). Early party policy was to denounce conservation measures as being part of bad colonial rule and the extension staff thus find it difficult to preach

soil conservation to people who have in their lifetime built conservation works and then destroyed them under different orders (TMA 5). As part of the second five year plan 1969—74, soil conservation measures once more appeared in government proposals. But the Ministry now mainly concentrates on introduction of new crops, new varieties and experiments concerning yields of crops using fertilizer, etc.

Earlier opinions on the causes of erosion

A wide variety of soils and an even wider range of types of agricultural practices are found in Tanzania. Causes of accelerated erosion in any one locale are often complex and while general comments on causes are common in the literature all too rarely have they been backed up by detailed study and analysis.

On the plains and plateau areas, accelerated sheetwash occurred where there was degeneration of pasture due to concentration of grazing in one particular area for long periods as in Ugogo area of Central Province or where there had been very heavy rain on unprotected arable land, for example, in the cotton growing area of Sukumaland (Van Rensburg 1942, ARA 1935). In the Kondoa area a combination of deeply weathered friable gneissic rock, and a sparse vegetation cover, in an area subject to periodic drought and intense rainstorms, was disasterous. The area which seemed untouched by accelerated erosion in the 1890s, became devastated over the next 30 years (Gillman 1930). Gullies developed, often along cattle tracks, but rapidly extended in the weathered gneiss and affected even areas which retained dense deciduous thicket vegetation. By the 1930s the area was considered irretrievable (TNA 4, TMA 1; Van Rensburg, 1958). Wind erosion occurred on arable land, where light sandy soils dried out quickly after rain, for example, in Singida District. Wind erosion was also a problem where mechanised large scale arable farming was introduced without the protection of windbreaks or strip cropping.

Staples (1933*b*) estimated that the cattle population of Tanganyika had increased from 1,650,000 in 1913 to 5,170,000 in 1930 though this latter figure at least seems highly overestimated. More recent estimates of cattle numbers are: 1950—6 million, 1960—8 million, 1965—10 million (Jensen 1968, p. 25). The increasing population density meant that people began to cultivate submarginal land and pasture became scarce. This necessitated long journeys to find food and water in the dry season and resulted in the trampling of vegetation and the use of marginal land as pasture. The result was exposure and subsequent erosion and depletion of soils which already had inherently low reserves of fertility. In the highland areas of the Porotos, the nature of the soils was such that "natural" erosion was claimed to be active everywhere in 1954 (TNA 9). The soils of the plains areas are light and easily worked but sheetwash was considerable in some areas.

R. A. Baker wrote, that "most Tanzanian soils are extremely erodible once the surface cover is removed." (Baker 1969, p. 42). The volcanic soils on the plains below Mt. Meru and Mt. Kilimanjaro are unstable and under permanent cultivation they became puffy and dry (Smith memeo undated).

Apart from these indigenous causes of erosion, government policies and efforts to control erosion often aggravated the situation when unsuitable conservation methods were used. In some cases, erosion was instigated where there had been none previously!

The agents of conservation and the conservation techniques adopted

Conyers in a recent study (1971) has identified over 200 significant agricultural systems in Tanzania. There are at least as many different agricultural environments in the country. Assuming some degree of interaction, one with another, there still remain a bewildering variety of man-land relationships, especially if we take into account the dynamic pattern of change in the agricultural systems over the last 50 years.

Many, if not all, indigenous agricultural systems were evolved in a precise relationship with the environmental, social and technological conditions of a particular time and a particular place. Most systems that have been studied in detail tend to conserve land, labor and other resources. Population growth, rapid increases in the livestock population, introduction of new crops and expansion of some agricultural systems to new areas have all contributed to imbalance and in some areas to erosional problems. Sometimes readjustments

Table 1. Mechanical measures used in Tanzania to counteract soil erosion
Symbols: + measures accepted by the peasants, S measures said to be successful by the colonial administration, – very unpopular measures.

Measures		Description
Contour hedging	+	The planting of trees, thicket bush or tall grass along the contour to stop soil movement downslope.
Contour ridging (Tuta cultivation).	S	The building up of topsoil into ridges along the contour-crops being planted on the ridges, which stop water movement downslope providing the plants on the ridges with adequate moisture.
Tied ridging[1].	S	The tying of contour ridges by building other ridges at right angles to the main ridges, producing a 'lattice-effect'. The crops were again planted on the ridge and water collected in the pits.
Matengo Pit System[2].	+	A similar idea to the above. Cut grass was laid in a grid of 7–10 foot squares. The centre of the squares were dug out and the grass lines covered with soil on which crops were then planted. Water collected in the pits and any soil washed off the ridges. After harvest the pits were filled in and the process repeated.
Trash bunding	+	Lines of trash were laid along the contour and plants were grown above on the hillside. Soil wash was collected in these lines of trash.
Contour banks	S	When enough soil had been deposited on trash bunds either by soil wash or by the farmer moving it—a bank was formed on which crops could be planted.
Narrow based terraces[3].	S +	In steep areas if more soil was washed downslope and caught by contour banks, the banks grew in size and eventually small terraces were formed. Some tribes were already using these before the government interfered.
Broad based terraces. Bench terraces.	– –	The significant difference between these two types of terrace and the narrow based was that they were larger and were constructed by actually digging soil out of the hillside. In doing so, the soil profile was disturbed and in most cases all the topsoil was used to construct the terrace. This led to their failure because in many cases after a few years all topsoil was washed away.
Boxed terraces.	–	The same principle as tied ridging, where smaller ridges were built at right angles to existing terraces to form boxes, where moisture collected. These involved a considerable amount of difficult construction work.
Gully stopping. Check dams		This process took many forms from the laying of brushwood across the floor of gullies to building actual concrete dams across the gully to check rapid water flow. The most successful were found to be where brushwood and stones were pushed right down into the floor and sides of the gully forming a barrier which trapped water and sediment in heavy storms. Afterwards water gradually seeped away leaving rich alluvial sediment which could be used to grow grass.
Diversion ditches. Stormwater drains.		The construction of ditches on slopes which were contour banked or terraced, or alongside roads and gullies to ensure constant flows of water during storms and avoid water building up which would then burst banks or terraces.

[1] A description of tie-ridging, contour banks and ridges (also called bunds and tuta cultivation), closing hilltops, contour hedging, grass stripping, mulching, windbreaks and the control of gullies appears in M. Lunan, 'Soil Erosion' in Rounce 1949.

[2] The Matengo Pit System is a system of laying out grass in the form of a grid of about 10 ft. squares. The centre of the squares are dug out to form a basin shaped pit and the grass lines are covered with the soil. Planting is on the ridges and the water collects in the pits. At the end of the season the pits are filled in with crop residues and the system repeated (Stenhouse, 1944).

[3] For a description of terracing in all its forms see 'Conservation of Soil Fertility on Coffee Estates' G. H. Gethin-Jones *E. A. A. J. Vol. I.* and for box terracing R. B. Alnutt 'Rice Growing in Dry Areas' *E. A. A. J.* Vol. 8, p. 103.

Table 2. Methods of improved land management also used to control erosion

In the mountain areas.	1) Reafforestation and non-felling of trees. 2) Non-grazing of stubble and stall feeding. 3) Non-burning of vegetation. 4) Closing hilltops and steep or eroded slopes to cultivation and planting perennial crops e.g. bananas and coffee. 5) Stopping shifting cultivation
In the plains.	1) Destocking and culling to obtain a good stock distribution and an adequate land carrying capacity. 2) Rotational grazing-establishment of grazing reserves. 3) Poisoning thornbush to promote grass growth. 4) Introduction of improved pasture plants e.g. legumes. 5) Building windbreaks.
General measures.	1) Depopulation moving people from overcrowded areas to areas of lower densities. 2) Grass stripping—leaving areas of grass between plots 3) Contour ploughing. 4) Manuring. 5) Non cultivation or grazing near roads, gullies or streams. 6) Grading, closure and/or realignment of paths, roads and cattle tracks.

of cultivation practices have locally redressed the balance, but this has proved more difficult in areas with animal husbandry.

Spontaneous responses to soil conservation needs

Increased population has in some parts of Tanzania resulted in marked changes in the use of land. The Wakara of Ukerewe Island in Lake Victoria have for many years suffered population pressure due to increasing population densities within the fixed limits of their island. The soils are sandy and to allow increasingly intensive cultivation the Wakara have adopted a number of anti-erosion methods such as tie-ridging and terracing, fencing of gullies and banking of streams (Thornton and Rounce 1936). For a description of these and other measures see Tables 1 and 2. The Wamatengo of Southern Tanzania and the Erok of Mbulu have both had to adapt their agricultural systems to different terrain, after being forced to live in steep mountain areas by the aggression of other tribes. The Wamatengo developed a system of pit cultivation, which is now commonly known as the Matengo Pit System and the Erok have developed a system of reinforced terracing (Hartley 1938). Some peoples have used agricultural techniques which, perhaps without their explicitly realizing it, have conserved soil. For example, in Musoma hedging was originally used to keep cattle off crops but it was recognized as a way of keeping the soil stable and fertile (Harrison 1938*b*). The Wafipa have a method of mound cultivation which also protects their soil from deterioration and therefore erosion (Lunan 1956). In 1930, the District Officer Morogoro commented that the idea of terracing was not foreign to the Waluguru, who had used terraces to cultivate steep slopes in the past (TNA 12).

From 1930 onwards the government at local and national level played a large part as an agent of soil conservation. But this did not mean that there was no new spontaneous soil conservation (ARA 1932). In general these local activities were on a small-scale, for example, trash bunding, building small banks/ridges and grass stripping. In the early days of organized conservation the peasant farmers were recorded as being most enthusiastic and receptive to new ideas (ARA 1934).

There is apparently no record of large estate-owners taking special steps to conserve their soil until 1937 (ARA 1937). But by the 1940s most sales of Rights of Occupancy were subject to the buyer promising to use anti-erosion measures on his land (ARA 1943). By 1954, in Kilimanjaro Region the main impetus for conservation came from the estate-owners (ARA 1954). This is explained in part by the greater amount of money available to them for the purchase of equipment to help conservation, whereas the ordinary peasant farmer had to perform the often arduous, but not immediately productive, work manually.

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Government activity

There were two levels of government soil conservation; that financed by the local government (the Native Authority) from their own treasuries and that which was financed from the Central Government offices. Most soil conservation measures in the 1930s and the early 1940s were locally administered and brought about by Native Authority orders. Central Government did not bring in any legislation for soil conservation until the late 1940s, when using the Natural Resources Ordinances, they introduced rules to allow the development of large-scale schemes.

Native Authority conservation

In the 1930s the Native Authorities were advised by the Department of Agriculture to adopt soil conservation measures in their areas. In practice this meant that the adoption of conservation measures was dependent on the initiative and powers of persuasion of the District Officer and the responsiveness of the chief and his council on the Native Authority. There is, of course, virtually no documentary evidence of the methods of persuasion used and in some cases it is probable that advice and persuasion on the part of the District Officer was accompanied by coercion. There are records in the government files of favorable and unfavorable receptions of the extension staff by the local people. At Mgeta in 1943, vigorous action by the subchief in posting extra instructors resulted in intensive conservation work (TNA 10). But only a few miles away at Morogoro the headmen were less willing to adopt conservation methods (TNA 3). When the chief at Kongwa saw the improvements made at Bwaga Dam, he requested the same treatment for his own area (ARA 1941).

The first areas to have conservation orders were usually those which were accessible to the Extension Staff, who were few in numbers. Thus it is probably not an accident that the first serious conservation took place in the Usambara Mountains, Mt. Kilimanjaro and Mt. Meru, and Bukoba, which are climatically the most pleasant areas of the country for Europeans.

In the 1940s, the main measures introduced in the plains were controlled grazing, by rotation and destocking of pasture land, depopulation and tie-ridging (box tuta) cultivation on arable land. Bush was poisoned at Msomalo to promote grass growth and "gully stopping" was introduced in other parts of Central Province (TMA 1). In the Dodoma and the Msomalo/Igandu Reclamation areas, the main efforts were concentrated on contour banking and ridging. Later, broad based terraces were introduced.

In 1951, a conference was held at Arusha on Land Development Schemes (TNA 7). It recommended: "In highland areas, erosion caused by overstocking should be controlled by stallfeeding and erosion caused by bad cultivation controlled by reafforestation. In lowland areas, there is a need first to determine the land carrying capacity of an area and then measures can be introduced to achieve a balance between population and stock."

By the early 1950s, the main focus was on the big new development schemes of the Central Government, but by this date most areas of the country had Native Authority orders governing conservation measures and although there was little mention of the fact, there was continued conservation work in areas not covered by the schemes. For example, in some areas of Sukumaland, not protected by the scheme there, hilltops were closed to cultivation and grazing, windbreaks and contour hedges were planted on arable land, which was already protected by tied contour ridges. Check dams were built in gullies and elephant grass was planted to give extra protection (ARA 1955). Native Authorities continued to introduce conservation orders until 1958 (TNA 8), three years before Independence.

Central Government conservation

As described earlier, in 1944 the government put forward a development plan for the Territory 1 3/4 million pounds being allocated to eight agricultural schemes, later increased to eleven. Three of the eight schemes were for land management in the plains, the most notable being the Masai Development Scheme and the Sukumaland Development Scheme. The other five schemes were for rehabilitation and protection of mountain areas, the main ones being the Ulugurus Land Usage Scheme, the Usambaras Scheme and the Kolo Rehabilitation Scheme.

The main aim of the schemes in the plains was to control population and stock densities in order to ensure that cattle numbers were kept below the land carrying capacity. The main object of the Masai Development Scheme was to supply water in such a way as to obtain a better distribution of the stock population, which in turn prevented trampling around watering points in the dry season leading to soil erosion in the wet season (Fuggles-Couchman 1964). This scheme was badly organized and poorly manned. The government went head first into building new water sources without forward planning. The Sukumaland Development Scheme involved more planning, having pilot areas to begin with, where land was divided into Land Usage Areas (L.U.A.'s) and detailed mapping and gazetteers were carried out for each L.U.A. Later population and stock were moved from densely settled areas and spread out over the greater part of Sukumaland. Complicated sets of rules were attached to cultivation, grazing and eventually most facets of agricultural life. There were rules on tie-ridging, manuring and burning. People were forbidden to cultivate near water, cut trees or move cattle without permission (Rounce 1949). By 1953 the Sukuma peasant thought he was being regimented, (Maguire 1969). He had to plant and harvest at a given time, he was told what to plant, he had to sell off his cattle and have the rest dipped and on top of this he was taxed and levied to pay for it (Maguire 1969). In areas like Ukzega where there was no room for stock movement into different areas, culling was thought to be the only answer for conserving the soil (TNA 7).

After the failure of the large schemes, there were only limited attempts at conservation by the colonial administration. In 1957 there were two schemes begun at Kasulu and Kibondo (TMA 5), to conserve soil moisture and fertility but these were more carefully controlled than previous schemes.

After 1961, although most agricultural and settlement schemes have incorporated some soil conservation there has been little specific emphasis on conservation schemes. In the Southern Highlands the Huhuri Land Use Scheme, linked the provision of rural water supply with soil conservation (ARA 1966) and the Ufipa Wheat Scheme, the Turkish Tobacco Scheme and the Kitulo Sheep Scheme all had some contouring and terracing (TMA 2). Also in Lake Province the settlement schemes at Galu and Rwamkona incorporated ridging (TMA 3).

The Land Planning Units of the Ministry of Agriculture have made efforts to introduce soil conservation measures in areas of known erosion. For example, when ujamaa villages were established in Arusha Region the Land Planning Unit gave advice on wind erosion problems and the adoption of stubble mulch (ARA 1969). They were more successful than the Land Planning Unit in the Usambaras who have had little response to advice on conservation apart from some contouring, even though political rallies have included lectures on conservation (TMA 6).

The successes and failures of the conservation measures and schemes

In the previous section the measures used by the colonial administration to diminish soil erosion in the semi-arid areas have been outlined.

The success or failure of the various measures adopted can be gauged in two ways: firstly by the actual success achieved by the colonial administration in physically stopping soil erosion in practical application and experiment, and secondly by the extent to which measures were accepted or rejected by the local people.

The colonial administrators viewed the success of conservation measures entirely from the amount of agricultural improvement achieved. For example, Fuggles-Couchman (1964) writes, that "in general the Sukumaland Development Scheme was (regarded as) a qualified success: its main achievements were the orderly settlement of large undeveloped areas accompanied by a greatly increased output of cotton and an increase in watering points".

However, the main problem of overstocking still remained. There were rapid improvements in pasture quality and bush regeneration when rotational grazing was introduced into the Msomalo area of Dodoma in the 1940s and two thirds of the population were moved to conform with grazing and cultivation rules (TNA 2). But when rotational grazing was

introduced without the construction of many new water sources, thousands of cattle converged on one spot for water in the dry season, trampling the soil and making it susceptible to extensive erosion in the wet season.

Much experimental work was done on the effectiveness of conservation techniques, in relation to crop production and soil conservation. At Ukiriguru, South of Mwanza, in the 1950s recorded yields of cotton and finger millet were found to be much higher on tied-ridges than ordinary ridges. On the sandy soils of Mwanza Region the runoff during storms was rapid and tied ridges proved to be the only successful conservation measure (ARA 1950). At Tengeru, trials were held for hill cultivation and the best yields were obtained from crops planted on tied-ridges or using the Matengo Pit System. In fact, in the Ulugurus, at Tengeru and Ukiriguru the Matengo Pit System had the acknowledged best yields but where rainfall was high tie-ridging was superior (ARA 1950). The Provincial Agricultural Officer, Dodoma, found check-dams with a core wall and bush pushed into the bottom of gullies the most successful technique for water storage in gullies because for months after the rains, water gradually seeped through and perennial grass grew below the dams (TNA 1).

Some measures obviously failed because they gave no improvements in crop yields, land fertility and soil stability. At Tengeru, trials proved too late that bench terraces led to disturbance of soil and drainage and the practice of planting elephant grass on the terraces reduced yields. Wider terraces took more man-days to build only to give worse yields. They also discovered that narrow-based contour banks led to considerable interbank erosion on slopes (ARA 1950). Gully stopping was found to be impractical if bush and trash were merely laid across the gully floor in lines, because the first storms swept it away, causing more erosion than was prevented.

The peasants actually accepted some of the proposed measures, but this was usually because the technique was familiar to them or because the measure was clearly going directly to benefit them. Contour ridging was said to be the most effective measure in Central Province, because the people agreed on the rationale behind it, making it relatively easy to implement (TNA 4). In the Usambaras, in the 1950s the rule against grazing of stubble was said to be popular with the women because it was their labor which was wasted when crops were trampled by cattle (TNA 5). Also in Northern Province and the Southern Highlands, the distribution of free seedlings was a success, because the people were getting financial improvement for no additional outlay on their part and reafforestation was one of the physically easier conservation tasks. This is probably also why live contour hedges are quoted as being the only mechanical method of conservation not regarded with disfavor in the Usambaras (TNA 5).

We have already seen that most conservation schemes failed in Tanganyika. However, the reasons for their failure cannot be found simply in an examination of the physical factors of the soil and environment. With some notable exceptions such as the use of terracing in the Ulugurus, most of the measures involved could have been successful in physically preventing soil erosion. However, the colonial administrators were wrong in their particular approach to the problem and it is here and in the reaction of the Africans to the colonial attitudes that we can find the reasons for failure.

Many of the measures actually adopted in conservation programs were unpopular with the people, because they cut across accepted agricultural practices. The peasants often had practical reasons for disliking measures. Wide grass strips and contour hedges were rejected because they used up too much land. In Mbeya, contour banks were unpopular because they led to infestation by rats (ARA 1948). People cleared their land because otherwise they had problems from tickborne diseases. Most peasants believed that burning improved their land, they were against the given alternative—manure because they thought it attracted weeds (Harrison 1938*b*). Cliffe (1964) maintains that the rules often challenged the peasant's economic security and his culture. In particular, the herding people were unwilling to part with their cattle, because they represented their wealth and security. Destocking was merely seen as a measure to benefit the underutilized factories of Tanganyika Packers in Arusha and Dar es Salaam (Cliffe 1961). Arable farmers were equally conscious

of their land rights and depopulation measures meant that people had to give up their inheritance.

Despite the large investment involved, there was a lack of planning for the large schemes. Technical officers rarely agreed on technical answers to the problems, so some had no enthusiasm for their work and if particular methods proved totally impractical changes in policy had to be made after a few years (TNA 7). Underestimation of staff needs led to half finished conservation works, lack of maintenance and little or even no supervision if staff were diverted to other activities such as famine relief. But for the administration, the most serious consequence of lack of staff was the lax enforcement of rules (TNA 3). The colonial administration could have partially improved matters by paying local people but they were unwilling to do this (TNA 4). Most officers reported resistance from the people because the work was usually too laborious (TNA 4).

Not only was there a lack of planning on the part of the administration, but they also failed to appreciate the culture and social organization of the various tribes of the country. Van Rensburg advocated that improvements should have been fitted into the tribal and social structure but this point seems to have been passed over by the administrators for they continued to press for depopulation of mountain areas and culling of cattle in pastoral areas (Van Rensburg 1942). Also the administration had not appreciated that many groups had adapted their agricultural system to their environment and could control soil erosion. Although scientific papers were written about indigenous conservation methods, there were few suggestions to use these in other areas. There was no attempt to adapt conservation methods to existing agricultural systems. For example, wide contour hedges failed where narrow ones would have been accepted by the people. Blanket measures were suggested for areas covering hundreds of square kilometers and these were enforced immediately without considering tribal and environmental variation at all.

All these factors combined to produce a strong element of mistrust among the African farmers for soil conservation. Soil conservation orders or rules applied only to the indigenous people, so the small farmer felt he was being discriminated against (TNA 7). Campaigns for extra production and soil conservation were often misconstrued by the local people to mean the Europeans wanted to exploit them and their soil (Cliffe 1964). Also rumors often spread when no one knew exactly what measures would be adopted.

Much has been written about the failure of the large development schemes in Tanganyika and authors are unanimous in their condemnation of the colonial government for their bad managenient (Cliffe 1964, Fuggles-Couchman 1964, Temple 1971, Young and Fosbrooke 1960). Comments on three of the schemes may illustrate the range of issues involved.

Fuggles-Couchman (1964) concluded that the Masailand and Mbulu Development Schemes failed because there was insufficient control of stock movements to and from the development areas. In particular, no provision was made for the control of livestock in the dry season and areas around watering points in Masailand were devastated. In Mbulu, operations had to be discontinued in 1953, when the development fund came to an end and the Native Authority could not take over the finance of a scheme of that scale.

Maguire (1969) states that the main reason for failure of the Sukumaland Development Scheme was the complexity and number of restrictions involved. There were rules attached to every facet of agricultural existence, many of which cut right across the accepted way of life. The administration, in particular, the Provincial Commissioner, did not show any understanding and were not interested in an idealistic program which was adapted to the people's needs (Maguire 1969). It was unfortunate for the administration that Sukumaland was the most politically conscious area of the country (Cliffe 1964) and failures were used to stir up the people against the colonial government. In 1958 there were many outbreaks of civil disobediance and the entire regimen of restrictive legislation was abolished in November of that year (Maguire 1969).

It is clear that many factors must be considered, before any soil conservation schemes are planned in the semi-arid areas of present-day Tanzania. The first obvious point is that detailed planning should be carried out before any scheme is started, to determine soil type and suitable conservation methods for the par-

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ticular environment. A number of measures are quoted above as being acceptable to the people and these should be used as far as possible. However, not only the physical environment needs to be considered. The great mistake made by the colonial administration was their virtual total disregard of tribal, social and cultural differences between the peoples of the country. In future, conservation schemes should be preceded by intensive adult literacy campaigns if the aim is to change the views of the people. For example, the Pares Community Development Scheme was partially a success because there was a literacy campaign before conservation was introduced (Fuggles-Couchman 1961). If this is not done, measures should be adapted to the existing system, as the people need to appreciate that operations are practical. They should be small-scale so that finance is not a constraint and if possible measures should be introduced which have immediate apparent benefits. The great overall need, however, is for integrated planning to ensure that schemes run smoothly and changes in policy do not have to be made after a few years.

Acknowledgements

The basic research for this paper was called out whilst both authors were members of BRALUP, University of Dar es Salaam, Tanzania. We much appreciate the support and co-operation of the Ministry of Agriculture and Co-operates and of the National Archives in this work.

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References

Published References

Alnutt, R. B., 1960: Rice Growing in Dry Areas. *East Afr. Ag. J.*, Vol. 8 p. 103.
ARA — Annual Report of the Dept. of Agric. Dar es Salaam Govt. Printer.
Cliffe, L., 1964: Nationalism and the Reaction to Agricultural Improvement in Tanganyika during the Enforced Colonial Period. Paper to the E.A.I.S.R. Conf., Makerere Univ., Kampala, Dec., 1964.
Corbel, J., 1964: L'erosion terrestre, étude quantitative. Methodes, Techniques, Resultats. *Annal. Geogr.* Vol. 73, p. 385–412.
Conzen, D., 1971: Agro-economic Zones in Tanzania. *BRALUP Res. Rept.*, Dar es Salaam.
Fournier, M. F., 1960: *Climat et érosion*. Presses Univ. France, Paris.
French, M. H., 1943: The Composition and Nutritive Values of Tanganyika Feeding Shifts. *East Af. Ag. J.* 8.
Fuggles-Couchman, X. X., 1964: Agricultural Change in Tanganyika 1945–60. *Food Research Institute*, Stanford Univ.
Gethin-Jones, G. H., 1900: Conservation of Soil Fertility on Coffee Estates. *East Af. Ag. J.*, Vol. 1.
Gillman, C., 1930: Notes on Soil Erosion in East Africa. Gillman Papers, Hans Cory Collection. Univ. of Dar es Salaam.
Harrison, E. H., 1935: Measures Against Soil Erosion in Tanganyika Territory. *East Af. Ag. J.* 1.
— 1938: Soil Erosion—A Memorandum by the Governments of Uganda, Kenya and Tanganyika to the Conference of the Governors of the East African Territories. Dar es Salaam.
Hartley, B. J., 1938: An Indigenous System of Soil Protection. *East Af. Ag. J.* 4.
Jensen, S., 1968: Economic Atlas of Tanzania. *BRALUP Research Paper No. 1.*
Luman, M., 1950: Mound Cultivation in Ufipa. *East Af. Ag. J.* 16.
Maguire, G. A., 1969: *Towards Ujamaa in Tanzania*. Cambridge Univ. Press, Cambridge.
Rounce, N. V., 1949: *The Agriculture of the Cultivation Steppe*. Longmans, London.
Staples, R. R., 1933b: Pasture Investigations in Tanganyika Territory. Dar es Salaam. Mimeo. Min. of Agric. Library, Pamba House.
— 1933, 1935, 1938: Run-off and Soil Erosion Experiments. *Ann. Rept. Dept. of Vet. Sci. and An. Husb.* Dar es Salaam.
Stenhouse, A. S., 1944: Agriculture in the Matengo Highlands. *East. Af. Ag. J.* 10.
Temple, P. H., 1971: Conservation Policies in the Uluguru Mountains. Paper No. 24, Proceed. Second Conf. on Land Use in Tanzania, 1971, Univ. of Dar es Salaam. In press.
Thornton, D. and Rounce, N. V., 1936: Ukara Island and the Agricultural Practices of the Wakara. *East Af. Ag. J.* 2.
Van Reenburg, H. J., 1955: Run-off and Soil Erosion Tests at Mpwapwa, Central Tanganyika. *East Af. Ag. J.* 20.
— 1958: Gully Utilisation and Erosion Control. *East Af. Ag. J.* 23.
Wood, A., 1950: *The Groundnut Affair*. Bodley Head, London.
Young, R. and Fosbrooke, H., 1960: *Land and Politics Among the Luguru of Tanganyika*. Routledge and Keegan Paul, London.

Unpublished References

Baker, R., 1969: The Soils of Tanzania. Min. of Agr. Dar es Salaam (Mimeo).
Harrison, E. H., 1938b: A Review of the Position in Regard to Soil Conservation in Tanganyika Territory. Report to the Agric. Div., Dar es Salaam (appears in TNA, 2)
Smith, R. (undated): Report on a visit to East Africa and Basutoland to study Soil Conservation Methods. Gold Coast Department of Agriculture.
TMA — Tanzania Ministry Agriculture File

TMA 1. P/SCH/CP — Land Use Schemes — Central Province.
TMA 2. P/SCH/SHP — Land Use Schemes — Southern Highlands Province.
TMA 3. P/SCH/LP — Land Use Schemes — Lake Province.
TMA 4. P/SCH/SHU/LD — Land Use Schemes — Shume.
TMA 5. P/SCH/NP — Land Use Schemes — Northern Province.
TMA 6. P/SCH/TR — Land Use Schemes — Tanga Region.
TNA — Tanzanian National Archives File
TNA 1. 19635 — (1931) Advisory Committee on Soil Erosion.
TNA 2. 46/20/26 Vol II — (1937–40) Regional Office Dodoma. Dodoma Soil Erosion.
TNA 3. 61/45/1/B/ Vol III — (1938–45) Agriculture Monthly Reports Morogoro.
TNA 4. 46/20/26/ — (1929–37) Dodoma Regional Office. Dodoma Soil Erosion.
TNA 5. 117/A/AR/D.5 — (1953–8) Regional Agricultural Office Tanga. Annual Reports Usambaras Scheme.
TNA 6. 215/10/14 — (1945–53) Shinyanga District Office. Sukumaland Development Land Utilisation.
TNA 7. 69/219/38 (1939–52) Regional Office Arusha. Agricultural Development Schemes.
TNA 8. 158/A/3/4 (1958–60) Mwanza Regional Office. Soil Conservation Schemes Ukara.
TNA 9. 327/A/3/E/Vol II — (1954) Mbeya District Office. Agriculture: Soil Conservation Eastern Division.
TNA 10. 61/45/1/B/Vol IV — (1945) Agriculture Monthly Reports Morogoro.
TNA 11. 125/5/1/(sic) (1932–49) Pastures.
TNA 12. 61/378/4 (1936) Regional Office Morogoro. Land Development Commission Reports on the Uluguru Hills Soil Erosion.
Van Reenburg, H. J., 1942: Pasture Development and Soil Conservation. Paper to the Regional Agricultural Officers in TNA 11.

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Stocking, M.A. 1978. Relationship of agricultural history and settlement to severe soil erosion in Rhodesia. Zambezia 6(2): 129-145.

RELATIONSHIP OF AGRICULTURAL HISTORY AND SETTLEMENT TO SEVERE SOIL EROSION IN RHODESIA

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Some 100 kilometres south-west of Salisbury, well away from the main road, lies a tribal area distinctive because of its severe erosion and its fine, white Karoo sand. Amidst gently rolling relief are found gully scars up to six metres deep and three kilometres long. The contrast in relief is remarkable; moving through the area, one meets slopes of no more than four degrees at one moment and a ravine with vertical sides dissecting the landscape at the next. More alarming than this static display of erosion, however, is the way in which these gullies maintain themselves. Gully-head cuts have within living memory advanced hundreds of metres, cutting roads, destroying vegetation, draining an already parched landscape and generally disrupting rural life. In short, it is a soil conservationist's nightmare; a badlands landscape reminiscent of a cross between the Grand Canyon and American dust-bowl conditions. One is tempted, as others have been, to point to the local population to lay the blame for this severe erosion. Is this fair? Can the erosion and contemporary rates of advance of the gullies be linked to the population and the way it utilizes the land?

Man has long been recognized as an important control variable in the erosion process. The evidence is irrefutable. While soil erosion is essentially a natural process governed by rainfall, soil conditions, slope and vegetation, man controls the system through the upsetting of the steady state. Usually this is through a destruction of the vegetation that promotes increased runoff and inadequate protection of the soil. The many means by which this can be done have been reviewed elsewhere.[1] In a Rhodesian context, aspects of man's influence on erosion have been discussed in an earlier article in this journal by the present writer.[2]

[1] L. D. Meyer and J. V. Mannering, 'The influence of vegetation and vegetative mulches on soil erosion', in *Biological Effects on the Hydrological Cycle* (W. Lafayette Indiana, Purdue University, Dep. of Agricultural Engineering, Proceedings of the 3rd International Seminar for Hydrology Professors, 1971), 355-66; M.A. Stocking and H. A. Elwell, 'Vegetation and erosion: A review', *Scottish Geographical Magazine* (1976), XCII, 4-16.

[2] M. A. Stocking, 'Aspects of the role of man in erosion', *Zambezia* (1971-2), II, ii, 1-10.

Against this view of man's over-riding influence on his soil resources must be set the fact that quantitative evidence is lacking. The degree to which man causes increased soil erosion is not known and, indeed, the exact mechanism by which the erosion takes place is little understood. Erosion modelling is in its infancy. Heinemann and Piest[3] report that the emphasis in the United States is increasingly turning toward developing comprehensive models that consider soil detachment and transport mechanisms in detail. The modelling and simulation of sheet erosion has received particular attention through a modified version of the Universal Soil Loss Equation incorporating hydrological variables,[4] and through mathematical simulation techniques.[5] If developed and co-ordinated, such models with appropriate and tested refinements hold promise of precise and logical explanation of both sheet and gully erosion, and we will have progressed toward 'the ultimate goal of watershed modelling',[6] deterministic models in which all cause-effect linkages and feedbacks are known and understood. Since neither the quantitative evidence nor practicable models (testing procedure) are to hand, there remains the real need to test emotive assumptions such as man's ubiquitous influence on erosion. Already evidence appears to favour a mixture of man and climatic change as being responsible in parts of the United States for severe gullying,[7] but local natural circumstances may still be of significant importance. The tenuous basis of much research to date is well summarized by Cooke and Reeves: 'almost all investigators have made an assumed relationship between vegetation and runoff, the cornerstone underlying their respective hypotheses'.[8]

This paper will seek by two very different avenues to determine man's role in promoting erosion in the headwaters of the Umsweswe River in central Rhodesia. Conclusions may be applicable to other badly gullied situations especially where most erosion is through deep, long gullies, variously termed as 'lavaka' by the French, as 'bocorocas' by South Americans, and

[3] H. G. Heinemann, and R. F. Piest, 'Soil erosion-sediment yield research in progress', *Eos Transactions* (1975), LVI, 149-59.

[4] G. A. Onstad and G. R. Foster, 'Erosion modeling on a watershed', *Transactions of the American Society of Agricultural Engineers* (1975), XVIII, 288-92.

[5] W. P. David and C. E. Beer, 'Simulation of soil erosion — Part I. Development of a mathematical erosion model', *Transactions of the American Society of Agricultural Engineers* (1975), XVIII, 126-9, 133; 'Simulation of soil erosion — Part II. Streamflow and suspended sediment simulation results', ibid., 130-3.

[6] K. J. Gregory and D. E. Walling, *Drainage Basin Form and Process* (London Arnold, 1973), 226.

[7] See R. U. Cooke and R. W. Reeves, *Arroyos and Environmental Change in the American South-West* (London, Oxford Univ. Press, 1976), which gives a wide-ranging review of the problem.

[8] Ibid., 7.

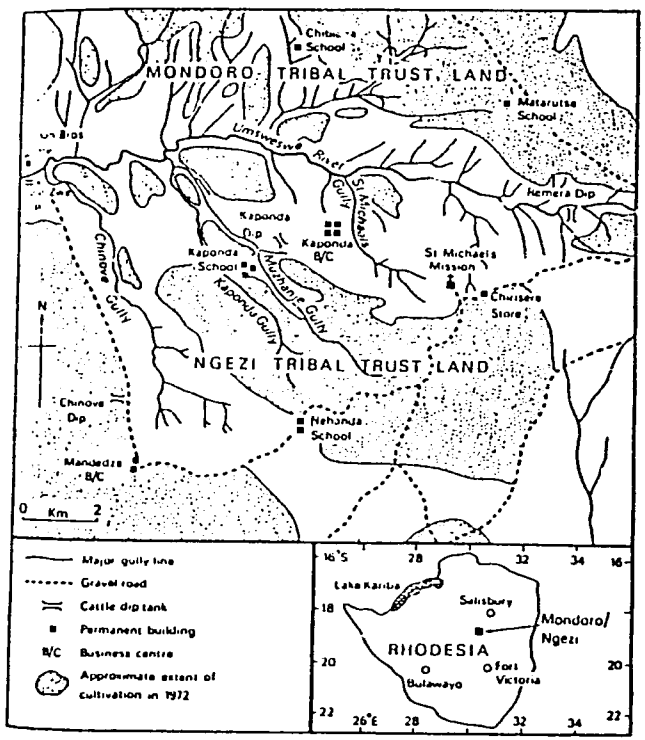

Figure 1: SITE AND LOCATION OF THE UMSWESWE CATCHMENT

as 'arroyos' by North Americans,[9] which are a peculiarly tropical and subtropical phenomenon occurring in fine-grained sands of a cohesive nature.

First, an examination is made of the history of early settlement and agriculture in Mondoro which includes the headwaters of the Umsweswe River to determine if there is any qualitative evidence to suggest man's involvement in erosion. Secondly, through a variable describing human pressure on the land, a statistical test is made of the relationship between gully growth and man. The study area is shown in Figure 1. It is a basin of deep Karoo sands underlain by granite. Archival records, interviews and experimental observation provide the main sources of information. The experiment on linking gully erosion to man is part of a broader study on the factors, both human and natural, that control rates of erosion; this wider study is unpublished[10] but the results are used in this account.

EARLY SETTLEMENT

Early Agriculture, 1890-1950. Native Reserves were set up in Southern Rhodesia at an early date following European settlement. Although it could fairly be said that in 1890 the whole country was available to the African population, the beginnings of land apportionment were very soon manifest. The Lippert Concession of 1891 provided for the selling and leasing of large tracts of land to incoming settlers. It could do so with relative impunity because the African population was small and the majority were in inhospitable country.[11] After the Matebele and Mashona rebellions of 1896-7, a Southern Rhodesia Order in Council (1898) placed the responsibility of providing sufficient land for Africans in the hands of the British South Africa Company. In practice this responsibility was devolved on to the district Native Commissioners and there was no standard practice in allocating land. As Palmer notes,[12] these African Reserves usually carry the connotation of land left over after European exploitation. Nevetheless it was widely believed at the time that the Reserves 'were not only sufficient but liberal, and will prove to be ample for the requirements of the native inhabitants for many

[9] M. Petit and F. Bourgeat, 'Les lavaka malgaches; Un agent naturel d'évolution des versants', *Bulletin de l'Association de Geographes Français, Paris* (1965), CCCXXXII-III, 29-33; J. Tricart, *Landforms of the Humid Tropics, Forests and Savannas* (London, Longmans, 1972); F. L. Prandini, 'Occurrence of "Voçorocas" in southern Brazil — geological conditioning of environmental degradation', *Proceedings of the 2nd International Congress of the International Association of Engineering Geology* (Sao Paulo, Instituto de Pesquisas Tecnológicas, 1974), I, iii, 36 1-36 10; S. A. Schumm, and R. F. Hadley, 'Arroyos and the semiarid cycle of erosion', *American Journal of Science* (1957), CCXXV, 161-74.

[10] M. A. Stocking, 'Erosion of Soils on Karoo Stands in Central Rhodesia with Particular Reference to Gully Form and Process' (Univ. of London, unpubl. Ph.D. thesis, 1977).

[11] G. Kay, *Rhodesia : A Human Geography* (London, Univ. of London Press, 1970), 47.

[12] R. Palmer, *Land and Racial Domination in Rhodesia* (London, Heinemann

years to come, even taking into consideration the rapid rate at which they and their stock increase, as well as their extensive methods of cultivation'.[13] By 1913 there were no less than 104 Reserves ranging in size from 2 000 to 600 000 hectares.[14] The situation is little changed today (although the area set aside for exclusive African occupation is rather greater at about 47 per cent of total land) and is enshrined constitutionally.

Against this background of land alienation must be set the rapid increase in African population accompanied by an even more dramatic increase in livestock over the whole country. In 1900 there were about 600 000 Africans with, it is estimated, 55 000 cattle. Through control of both human and cattle diseases by 1945 there were some 1,75 million Africans with 1,9 million cattle.[15] Today an African population of 4,5 million (40,4 per cent in urban areas and, therefore, holding no cattle) has well over 2 million cattle, about 650,000 goats and numerous other small stock. Both Kay and Palmer[16] document the serious deterioration in the man-land ratio without any compensating improvement in man-land relationships. Indeed, changes in land usage such as the change from traditional foodstuffs and hunting to maize monoculture and cattle keeping have added to pressures on the land. For instance in 1900 it is estimated that the cultivated area was 0,43 ha per person. By 1945 it was 0,48 and by 1962 it had risen to 0,71 ha per person.[17]

Though little documentary evidence remains, the Umsweswe catchment was never settled by Europeans as the soils are relatively infertile and the area is away from the main gold-producing districts which attracted most early attention. From what must have been a very sparse population at the turn of the century the area for African settlement was compressed into the Mondoro Reserve with large tracts of land either side of European settlement along the Salisbury-Hartley-Que Que-Bulawayo and Salisbury-Enkeldoorn-Fort Victoria axes. In the first two decades of this century there were considerable influxes of people; not only those dispossessed of their land but probably more importantly those moving from districts infested by tsetse fly. For example it was noted in 1915 that 'on account of the Fly people were moved from the Sanyati-Umfuli area to near the Zwezwe River in Mondoro'.[18] Several such population movements are mentioned, other factors being tribal disputes and the natural search for better lands,

[13] Quoted in ibid., 60.
[14] Kay, *Rhodesia*, 49.
[15] Ibid., 48, 79. Figures for African-owned cattle are problematic. Palmer, *Land and Racial Domination*, 91, cites approximate figures of 41 000 in 1901 and 1,8 million in 1951 with specific counts of 195 837 in 1903 and 406 180 six years later. The impression of exactness is spurious but the increase is nonetheless dramatic.
[16] Kay, *Rhodesia*, 79-93; Palmer, *Land and Racial Domination*, 96-8.
[17] Kay, *Rhodesia*, 80.
[18] National Archives of Rhodesia, Salisbury, NSE/4/2/1 (N[ative] C[ommissioner] and Magistrate, Hartley : Reports : Monthly : Sept. 1912 Dec. 1919), Month ending 31 Dec. 1917. All documents cited hereafter are in the National Archives unless other-

all of which add to a sizeable influx of people. In 1915 it was estimated that some 19 acres (7,5 ha) were available for each African and it was remarked that this was 'exceedingly good';[19] it does not, however, compare favourably with the countrywide average in 1962 of 8 ha per person in the Tribal Trust Lands. Some areas close by remained unsettled by Black or White farmers; the Native Commissioner, Hartley, noted in 1921 that an area to the south of the Umsweswe River and a little to the west of the study area was 'clear of natives and may be alienated'.[20] Such alienation probably only served to further restrict available land and increase the effective population pressure.

Comments in reports on early conditions and standards of agriculture are highly subjective but there are many references to the difficult physical conditions in Mondoro, though no mention whatsoever is made of the gullies. In 1918 it was reported that 'the natives living in the sandy parts of Mondoro were not reaping much from their lands because it became so wet and crops failed to mature'.[21] The destruction of crops by game animals seemed an ever present problem and swarms of locusts were sometimes noted in 1925. The area surrounding the Umsweswe River was described in 1925 as a 'moving mass of hoppers'.[22] Apparently 2 453 separate swarms were destroyed that year with the help of adjacent European farmers whose interests might have been prejudiced.[23] All these 'natural' hazards appear to have reduced the state of agriculture in the first three decades of the century to a poor and parlous condition, exacerbating man-land relationships.

By the 1930s the situation appears to have become more stabilized. At least one agricultural demonstrator was active in the area and Native Commissioner's reports note fairly good crops and good responses to attempts at improving standards of agriculture.[24] There was, however, mounting concern over grazing land pressures. A letter from the Agriculturist, Native Department, to the Chief Native Commissioner, of 18 April 1934, reported

[19] NSE/2/3/1 (N.C. and Magistrate, Hartley : Out Letters : Superintendent of Natives, Salisbury : 18 Nov. 1913-14 Mar. 1917), Ngizi Reserve, 19 Mar. 1915 : A remark by the authorities not by the populace.
[20] NSE/2/3/2 (Out Letters : 15 Jan. 1920-23 Dec. 1922), Circular from N.C., Hartley, 'Reverted Reserves', 9 Mar. 1921.
[21] NSE/1/2/1, Report, 13 June 1918.
[22] S1032 (Ministry of Agriculture, Salisbury : Correspondence : N.C., Hartley, 1906-25), letter from N.C., Hartley to C[hief] N.C., Salisbury, 14 Jan. 1925.
[23] The whole campaign against locusts in the Charter District is documented in S1827/1425/1/8 (Ministry of Agriculture, Botany and Plant Pathology, Correspondence and Other Papers, Numerical Series, 1904-58 : Locust Campaign, Charter, 30 Sept. 1932-24 Feb. 1943).
[24] For example, S138/72 (C.N.C., Correspondence, Numerical Series, 1923-33 : Agricultural Activities within the Department of Native Development, 1927-33), D26/30, Alvord to Director of Native Development, 27 May 1930. Considerable local interest was being shown in 'Before Harvest Meetings'.

that the overgrazing, especially in the northern sector of the Mondoro Reserve, was particularly bad, and so recommended control of grazing and the migration of people to south of the Umfuli River and into the Umsweswe catchment.[25] At the same time there was also a general increase in awareness of soil erosion especially in the Native Reserves which culminated in the Report of the Soil Erosion Committee of the Rhodesian Agricultural Union in 1932[26] which drew heavily on early American experience in erosion. Yet no specific mention is made of the gully erosion in the Umsweswe catchment. Several indirect references are to be found and one report illustrates well the paternalism of the era:

> The natives are simply running wild and ploughing up large areas of land every second year. Not only are they ruining good soil through bad farming but destroying all the valuable timber. This is country that can support a lot more natives if properly settled. The main offenders here are non-indigenous natives who have cleared acres and acres of the best soil, farming it very poorly and working it as though it was a private farm . . . There is no rotation of crops and no manure applied which means he will soon be looking for another 100 acres of good soil to ruin.[27]

There were also other problems to contend with. At times the Native Department agricultural demonstrators, though Africans themselves, were unpopular, it is alleged because of their involvement with Mission schools.[28] However, Demonstrator Dawa in Mondoro seems to have overcome this problem by 1933 and had 346 'co-operators' who were following approved agricultural methods including manuring, using improved maize seed and practising rudimentary conservation measures. Increased yields and the production of surplus maize gave rise to a further problem which exists even today: marketing and transport.[29] The Reserves are usually some distance from main communication routes and the poor state of the roads and lack of marketing facilities obviously retarded any attempts at production of surplus produce. This general problem is seen today in declining productivity in the Tribal Trust Lands and a money economy unable to absorb the increasing rural population.

Boundary Change and Administrative Responsibility. The limited awareness of soil erosion and in particular of the gullies, coupled with a general lack of any documentary information south of the Umsweswe River has already

[25] S1542/A4 (C.N.C., Correspondence, General, 1914-43 : Agriculture, 1933-9, Reports and Surveys on Reserves), I.
[26] Ibid., unpubl. report, mimeo, 14pp.
[27] Ibid., III, Inspection Report of Assistant Agriculturist, G. R. Polner to C.N.C. Salisbury, 26 Mar. 1938.
[28] S138/72, Agricultural Status of Reserve Natives, H. Jowitt, Director of Native Development to Superintendant of Natives, Fort Victoria, 14 Feb. 1930.
[29] Ibid., Report on Before-Planting Inspection of Demonstrator's Plots on Reserves Season 1932-3, Alvord to C.N.C., undated. Alvord notes that, 'demonstration work has taken a set-back because plot owners have not been able to sell the improved maize grown on plots and are wondering if it is worth while to give up the old easy methods and do the hard work required on plots'.

been noted. No obvious reason is to hand as the area was certainly settled by Africans prior to 1918 and even as early as 1899 administrative responsibility was apportioned to the various district offices. The answer to the lack of information probably lies in two related reasons; first, the distance and poor communications from the nearest district offices (Hartley to the north-west and Fort Charter or Charter at the Range to the south-east); secondly the history of boundary changes in the area and later changes in responsibility for different aspects of native agriculture.

In 1899 the boundary between Hartley and Charter Districts was taken to be the 'Umgezi' [Ngezi] River[30] which runs parallel to the Umsweswe and to the south of the study area. The Umsweswe headwaters were therefore in the Hartley District. This boundary was reaffirmed in 1909[31] although some documents in the interim appear to show some administrative functions carried out by the Native Commissioner at the Range (Charter). Hartley is some 95 km from the study area but 175 km by road, most of it on poor dirt. That is the situation today; in 1900 all administrative communication was by horse and the Umsweswe catchment was on the very periphery of the Hartley District unconnected except by bush path and seldom visited.

In 1920 the boundary between Hartley and Charter Districts was moved north to the Umsweswe River[32] and about this time all native land to the Ngezi River was named Mondoro Reserve and land south of the Ngezi named 'Umgesi' Reserve. By 1935 the Southern Rhodesia 1:1 million map shows the area south of the Umsweswe, now called 'Umgezi and Mondoro South', in 'Charter at the Range' District and the area north of the Umsweswe, called 'Mondoro North', as being in Hartley District.

After 1935 the situation is confused and staff shortages especially in agricultural personnel necessitated the grouping of areas which took little account of then existing boundaries. Because of its outlying position the Umsweswe catchment appears to have been sadly neglected, being rarely mentioned.

The final documented changes in administrative responsibility arose from the 1961 Southern Rhodesia Constitution where all African lands were grouped together to form larger blocks of land to be known as Tribal Trust Lands.[33] The area south of the Umsweswe River (Ngezi T.T.L.) now found its administrative headquarters under the District Commissioner at Gatooma, some 40 km south-west of Hartley. Mondoro T.T.L. north of the Umsweswe remained with Hartley although it does appear that one Agricultural Officer served the two District Commissioners at Gatooma and Hartley for the whole

[30] Southern Rhodesia, Govt Notice 13/1899.
[31] Southern Rhodesia, Govt Notice 131/1909.
[32] Southern Rhodesia, Govt Notice 146/1920.
[33] Southern Rhodesia, Govt Notice 518/1963.

of Mondoro and Ngezi. At around this time also responsibility for African agriculture, which had for many years been with the Ministry of Agriculture (dealing both with African and European agriculture), was transferred to the Ministry of Internal Affairs which now had sole responsibility for all aspects of the tribal areas. Many agriculturalists considered this a retrograde step, especially as many of the experienced Agricultural Officers remained with the Ministry of Agriculture dealing with European farming alone. The extra responsibility placed on Internal Affairs field staff was great and inevitably expertise in agricultural matters suffered.

The Land Tenure Act of 1970 finally fixed the sizes of Ngezi T.T.L. as 56 900 ha and Mondoro as 130 500 ha, the situation pertaining today.

The sorry history of administration of the Umsweswe headwaters contrasts with the tighter control exercised in areas closer to the main district offices. A large part of the mismanagement and general neglect of the area can perhaps be related to these administrative changes. How far this neglect through administrative change affected erosion is uncertain. It was not until the 1950s with the implementation of the Land Husbandry Act that there was any concerted effort at finding out the problems of the area.

LAND HUSBANDRY ACT

The Native Land Husbandry Act of 1951 was the product of mounting concern over the deterioration of the tribal areas and unworkable earlier legislation such as the Natural Resources Act (No. 9 of 1941). The new Act provided regulations for enforcing conservation and good farming with serious penalties for offenders. It also provided for the assessment of the carrying capacity of each tribal area and the redistribution of arable holdings. Since the data base for much of the implementation of the Act did not exist, each area had to convene an Assessment Committee which met to consider the overall picture. The information collected for each committee would consist of a census of people and animals, areas of arable land, historical background of tribes and general impressions of the state of the agriculture. Information varied in quality but it seems that that for Mondoro South was good.

The Assessment Committee for Ngezi-Mondoro Reserve met on 12 September 1956.[34] They divided the Reserve into three, the northern zone closely corresponding to the study area south of the Umsweswe River. This northern zone was approximately 175 km² with a population estimated at 5 500 giving a density of about 31 persons per square kilometre. However, the point was made that some half of the male population was out of the Reserve and working in towns leaving a resident male population of only 532; the effective population density is then less than 29 persons per square kilometre. Other pertinent 1956 data are shown in Table I. It should be noted that many of the figures are probably grossly underestimated to reduce tax assessment and cattle dipping fees. It is impossible to estimate the numbers of 'hidden'

people and livestock but experience elsewhere indicates that the underestimation for cattle could be of the order of 50 per cent.

Through the Land Husbandry Act the only comprehensive count of populations was carried out. As such it was an extremely useful exercise although many of the recommendations based on the collected data failed to materialize into firm changes in land use and practice. Perhaps the only real changes were firstly a maintenance of approximately 4 000 head of cattle in the area until today (a ratio of one beast to 4,37 ha) and secondly a fairly drastic reduction in cultivated area. These moves seemed also to stem increase in human population at the expense of areas further to the south.

Table I

STATISTICAL INFORMATION ON THE NORTHERN SECTOR OF NGEZI RESERVE

Human population	5 500
Total number of:	
cattle	4 [illegible]
calves	500
donkeys	162
sheep	213
goats	287
large stock equivalent	4 294
taxpayers	1 250
resident males	532
kraal heads	61
stockowners	686
landholders	1 038
Cultivated area (ha)	5 216
Proportion cultivated land to grazing land	30
Number of stockowners owning:	
1 - 3 cattle	121
4 - 6	300
7 - 9	168
10-12	69
13-15	18
16-18	9
19-21	1

[34] Relevant data for consideration by the Assessment Committee was submitted i an unpublished report from R. E. Jenkinson, Land Developemnt Officer, Aug. 195 (now held by District Commissioner, Hartley). The findings of the Committee occu in : Minutes of Meeting of Assessment Committee for Ngezi Mondoro Reserve in th Charter District, unpubl., Sept. 1956 (held by Minister of Internal Affairs, Salisbury). The latter is largely a copy of Jenkinson's report.

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RECENT EROSION AWARENESS

As the population of the Umsweswe catchment grew and the area was opened up, the gullies did start to attract attention because of their sheer size. Other aspects of erosion were neglected.

The earliest attempts at dealing with the gullies were as a result of a meeting of Native Department and conservation staff at Hartley in 1946 or 1947.[25] From this meeting a series of large contour banks designed to a gradient of 1:600 were built around the heads of St Michael's Gully (then called Timba Gully) and a few of its tributaries. These banks were so massive that they are clearly evident today on the ground. St Michael's Gully has progressed through the first bank and one of its tributaries is now following the contour on the upstream side of the bank. Without doubt it was the worst course of action that could have been taken since the contour banks served only to concentrate surface waters and led to preferential infiltration and the development of tunnels

Also at this time three dams were built (none surviving now) for stock watering to reduce concentrations of cattle along the river banks. The heads of the gullies were fenced but it appears that the fencing material was stolen within one or two years and the members of the Assessment Committee for the Land Husbandry Act were unaware of its existence in 1956.

It was not until 1969 that the authorities showed any firm resolve to tackle the problem of advancing gullies. A series of Ministry of Internal Affairs departmental reports and memos in 1970 and 1971 leave a record of unfortunate recommendations and conclusions.[26] For example, despite an adverse report from the Rhodesia Forestry Commission on the planting of trees in the immediate vicinity of gullies[27] several belts of exotic trees were planted. Their growth has been minimal and has probably only retarded grass growth within the belts. Much was also written on the mismanagement and overgrazing of the catchment with little evidence to support such a contention. The result was an expensive programme of fencing the gully heads to allow regrowth of grasses with minimum grazing; the D.C., Hartley, reported in 1969 that 39 miles of fencing were recommended at £100 per mile.[28] The fencing programme has continued through to 1975 with further considerable cost. Since the fencing depends on both regular maintenance and the closing of the few main gates into the enclosures, the onus for success

[25] F. Micklesfield, retired Agricultural officer, personal communication, 17 May 1976.

[26] Ministry of Internal Affairs, Salisbury, AGR/5/50 (Correspondence and Reports, 1967-71), Soil Conservation Special Project Ngezi Tribal Trust Land and Mondoro Tribal Trust Land

[27] Rhodesia Forestry Commission, Ref. 399, 'Tree Planting for Gully Reclamation, Memo from T. J. Hodgson, Forest Officer, 29 Jan. 1971

[28] Ministry of Internal Affairs, Salisbury AGR/7/12/69, Gullies : Hartley and Gatooma, Woollacott to Provincial Commissioner, Mashonaland South, 21 Nov. 1969.

of the scheme was placed on local tribesmen, a responsibility not appreciated by many. Certainly by 1974 the fencing was relatively ineffective and no measured differences in grass cover were found inside and outside fenced areas, indicating that cattle were effectively free to graze at will.

Recently the Natural Resources Board has taken an interest in gully reclamation. A series of stone bolsters have been placed in the base of St Michael's Gully and in several of the heads of the Chinove-Bhiza section with finance raised by the Natural Resources Board. The bolsters consist of ironstone wrapped in chicken wire. Some considerable sedimentation has occurred upstream of the bolsters and the floor of St Michael's Gully near its head cut is now 75 cm higher. However, the cost of construction of the bolsters and subsidiary efforts such as planting and watering of grass has been exorbitant. While it has been demonstrated that some sedimentation has occurred, the effective gain in land has been negligible and the advance of the head cuts has hardly been retarded. Without the sizeable grants from Government sources, any reclamation would be impossible and it is felt that any workable scheme is financially impractical. To date the programme of stone bolsters is continuing. Other less successful (or even disastrous) attempts have been discontinued, examples of which were the bulldozing of head cuts to smooth the profile (the head cut in one instance reinstated itself after one storm) and the planting of sisal.

From all of these more recent experiences it may be concluded that little real practical benefit in land reclamation has been achieved. The focus of attention has always been the head cut and the immediate gully base. The catchments have been largely neglected because perhaps by comparison with other tribal areas they are fairly well covered by vegetation. Finally, there has been very little recognition that the gullies might conceivably be primarily a product of natural processes. The erodible nature of the soils is occasionally mentioned but the blame has all too readily been placed on local tribesmen for mismanagement of the land — a factor which is not necessarily supported by observational evidence and enquiry.

QUANTITATIVE ASSESSMENT

The evidence from a study of the history of occupation of the area suggests that while mismanagement and administrative neglect have occurred, the population has never been excessive and no extraordinary man-induced influences may be invoked to account for severe erosion. It remains, however, to determine if contemporary erosion may be aided by pressure of population on the land. The most obvious means of doing this is to compare rates of advance of gully head cuts between catchments with differing population pressures. Since catchment variables such as area and vegetation cover are also likely to be different between catchments, it is necessary to take these into account in a multiple regression model along with the human factor. It is reiterated that the purpose of this paper is to test man's influence on

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erosion; the other variables are introduced only for statistical rigour and their significance is reported on fully in my unpublished thesis.[39]

A Variable for Population Pressure. The choice of a parameter to measure population pressure in problematic. On the one side, it is not known how man affects erosion; on the other, it is not known how much pressure land can sustain without irrevocable damage. Carrying capacity formulae have been designed[40] but all are based on untestable assumptions and data that are not always available. A proxy variable for population pressure is necessary which integrates the many unknown linkages. In a study of differences between types of land tenure, population densities and severity of erosion, it was found that in most instances population density was related to erosion.[41] In the present study all catchments to gullies are wholly within one type of land tenure, the communal grazing and small arable plots of the Tribal Trust Lands. Therefore, the major difference that may have a bearing on erosion between catchments is the numbers of people making use of the land. The main assumption is that every person through his practices and through the grazing animals he keeps affects erosion equally. That this is not so on an individual basis can be demonstrated by comparisons of sheet erosion and declining fertility on adjacent smallholdings; farming has multiple objectives and multiple paths to reach those objectives. Nevertheless over large groups of peoples the averaged effect should approximate to the assumption, and population density be a suitable proxy variable for man's influence on erosion through farming practice.

Population density was measured on a square kilometre grid basis by 100 per cent count. From Figure 2 it can be seen that the density is quite variable (between 0 and 130 persons per square kilometre) depending on the location of the larger village groupings on the edge of the arable lands and along the main watershed boundary roads. Mean population density in 1974 was 31,4 persons/km² indicating a slight increase over 1956. The total population was 5 645 with a rather greater density (34,1) south of the Umsweswe River than north of it (25,8).

Other Variables of Gully Growth. In the multiple regression model, population density, D, represents one of the independent variables. The others are:

[39] See footnote 10.

[40] W. Allan, 'How much land does a man require?', in *Studies in African Land Usage in Northern Rhodesia* (Lusaka: Rhodes-Livingstone Institute, Paper No. 15, 1959), 1-23; R. Feachem 'A clarification of carrying capacity formulae', *Australian Geographical Studies* (1973), XI, 234-6.

[41] Stocking, 'Aspects of the role of man in erosion'.

[42] I. Seginer, 'Gully development and sediment yield', *Journal of Hydrology* (1966), IV, 235-53; J. R. Thompson, 'Quantitative effect of watershed variables on rate of gully-head advancement', *Transactions of the American Society of Agricultural Engineers* (1964), VII, 54-5.

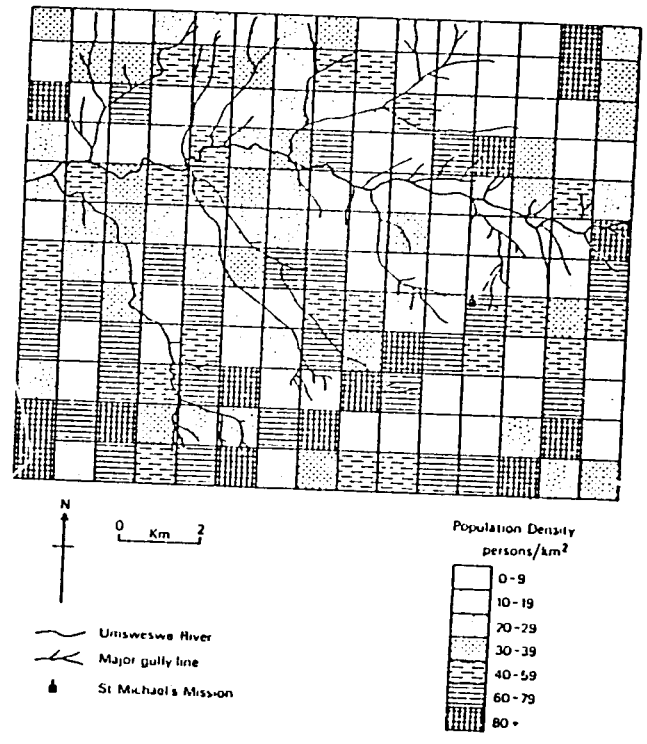

Figure 2: POPULATION DENSITY OVER THE UMSWESWE CATCHMENT.

Precipitation, P mm
Antecedent precipitation index, A_p mm
Catchment area to gully head, A_c km²
Mean vegetation cover, C %
Height of head cut, H m
Slope of approach channel, S degrees

While many other variables could have been used, of those chosen some are ones that have been found important elsewhere[42] and others would have a high degree of interdependency with extra variables. Gully growth is measured by the volume of soil removed from the head cut after each storm event, Y m³.

Results. Using a step-wise multiple regression procedure whereby the least significant contributory variables (based on t-value) are progressively dropped, the most significant variable remains. At the same time the contribution of the other variables towards explanation of gully growth may be monitored (Table II). A sample of gully heads retreating principally through waterfall erosion was used; the wider study, of which this is a part, also considered other head cuts at different time scales. Results are broadly similar to the ones reported here in Table II.

The most significant individual variable is A_c (product-moment correlation coefficient, $r = 0{,}686$), followed by H (0,606), A_p (0,535) and P (0,351). Variables C, D (population density) and S are nearly randomly correlated with gully growth and are eliminated at an early stage in the step-wise regression. Interaction between the other variables, P, A_p, A_c and H gives an equation that explains 80,1 per cent of the variation ($R = 0{,}895$). With a 10 per cent loss in explanation ($R = 0{,}844$) A_p may be eliminated to give what is probably the optimum prediction equation for these gully heads:

$$Y = 6.87 \times 10^{-3}\ P^{1.34}\ A_c^{1.00}\ H^{0.53}$$

Discussion. Population density fails to improve the prediction of head cut growth and, by itself, has a very low correlation with gully growth ($r = 0.018$). The reason for this is either that population density is an ineffective measure of population pressure on the land or that population pressure is not an important contributory factor to erosion under the conditions investigated. It has already been argued that population density is likely to be a crude but significant parameter for population pressure, and, therefore, the latter explanation is preferred. Indeed, the results suggest an essentially natural basis for gully formation in the area and no discrimination is found in rates of erosion between catchment areas with high population density and those with low density.

[42] M. A. Stocking, 'Tunnel erosion', *Rhodesia Agricultural Journal* (1976), LXXIII, 35-9.

Table II

GULLY GROWTH PREDICTION EQUATIONS FOR WATERFALL HEAD CUTS

Regression	Degrees of Freedom	Multiple Correlation Co-efficient R	t—values of Variables						
			P	A_p	A_c	C	D	H	S
$Y = 2{,}55 \times 10^{-3}\ P^{1.02}\ A_p^{0.56}\ A_c^{0.90}\ C^{-0.28}\ D^{-0.09}\ H^{0.48}\ S^{-0.29}$	40	0,902	4,06	4,41	4,95	—1,05	—0,41	4,67	—1,30
$Y = 2{,}03 \times 10^{-3}\ P^{1.01}\ A_p^{0.56}\ A_c^{0.90}\ C^{-0.31}\ H^{0.47}\ S^{-0.29}$	41	0,901	4,08	4,52	4,99	—1,19	—	4,76	—1,31
$Y = 4{,}97 \times 10^{-3}\ P^{1.06}\ A_p^{0.52}\ A_c^{0.85}\ H^{0.49}\ S^{-0.23}$	42	0,898	4,30	4,34	4,82	—	—	5,12	—1,05
$Y = 4{,}14 \times 10^{-3}\ P^{1.07}\ A_p^{0.63}\ A_c^{0.86}\ H^{0.50}$	43	0,895	4,40	4,39	4,86	—	—	5,22	—
$Y = 6{,}87 \times 10^{-3}\ P^{1.34}\ A_c^{1.00}\ H^{0.53}$	44	0,844	4,73	—	4,86	—	—	4,52	—
$Y = 4{,}42 \times 10^{-3}\ P^{1.13}\ A_c^{1.47}$	45	0,760	3,37	—	6,91	—	—		—
$Y = 3{,}5 A_c^{1.60}$	46	0,686	—	—	6,40	—	—	—	—

Note: Series of regressions follows the step-wise procedure giving equations with the higher multiple correlation coefficient with a give number of variables.

CONCLUSIONS

There is neither firm historical evidence nor contemporary experimental and statistical evidence to support the contention that man has largely brought about the severe erosion in the Umsweswe catchment. Historically, it has been shown that the population has remained fairly static over recent years, having risen gradually from the mid-nineteenth century. Cattle and livestock populations likewise have little changed. There are some documented agricultural difficulties, such as locust swarms, administrative neglect and unwise conservation treatment of the gullies, but these cannot solely account for the formidable erosion manifest today.

This qualitative view is supported by experimental evidence of rates of erosion compared to population pressures within the catchments to the gullies. From a large sample of gully heads and individual storm events there is no basis for present high population densities to be the cause for measured rates of gully advance. It may be that if population were to continue to increase above some threshold, gully advance would also increase but this threshold, if it exists, has not been reached by existing population densities.

Care must be taken in applying the results to other situations. Certainly the variety of valley bottom gully characterized by steep or vertical walls in cohesive fine sediments and flat wide floors, and variously called 'lavaka', 'arroyos' or 'bocoroces', should not immediately be taken as evidence for mismanagement of the land. As in the case studied, these gullies are probably a natural response to changing environmental conditions. This is not to say that man may not aggravate the conditions; he often does, but he is not the principal cause. Similarly, other forms of erosion may be natural responses to particularly erosive conditions. In the tropics, soil types are often responsible for serious tunnel erosion.[43] Other cases may come to light. At the same time, man's role should not be diminished. He is undoubtedly responsible for many if not most cases of land degradation. But he may not be responsible for all. There exists a wide field for research in erosional processes and forms in the tropics.

ACKNOWLEDGEMENT

Funds for this research were provided by the Research Board, University of Rhodesia.

Mbithi, P.M., and D. Kayongo-Male. 1978. Local environmental perception and soil and water conservation practices. In Soil and water conservation in Kenya. Occasional Paper no. 27,102-4. Nairobi: Institute for Development Studies and Faculty of Agriculture, University of Nairobi.

INTRODUCTION

The Role of Local Communities in Conservation

Many construction engineers are convinced that those personnel who are going to be involved in the long-term maintenance of structures must be intimately involved in their construction. In this way they will be familiar with the anticipated operational and structural weaknesses. With roads for example, those involved in construction will become familiar with every foot of the road, where the ballast is weak, where a culvert may be insufficient, etc.

In soil and water conservatio structures, the basic unit involved is the farm. An adequate farm plan represents investments in dams, cutoff drains, terraces, windbreaks, woodland, permanent pastures and a cropping regime which is consistent with the goals of fertility build-up and conservation. The farmer and his household are the active agents in building such structures and in maintaining them. In cases where governments intervene to enforce the construction of such structures or even construct them with or inspite of farm household participation, the long-term goal is for the farm household to maintain such structures and integrate them into farming operations and farm resource utilisation. The need for this household to be involved and understand the environmental and economic rationale of such structures is obvious if they are to maintain them and integrate them effectively in their farm operations.

In certain cases, local villages or 'communities' are the basic units involved. In dealing with the special problems of a catchment zone, specific watershed, river course, inter-farm paths or tracks, then one involves more than one farm household and the need for community involvement is the same.

The participation of local communities in conservation is further supported by economic and sociological evidence. In current development funding, provision is made for mobilising local resources in the spirit of Harambee (self-help). Such local resources include local unskilled and semi-skilled labour, local farm tools and draught power, local organisational ability and leadership skills, and materials in kind such as sand, stones, grass splits and seeds. Participation of local populations in soil conservation is seen as critical in increasing local commitment and identity with the goals of the conservation programme. Such commitment eliminates suspicion, apathy and indifference and legitimises the sacrifice of personal energy and farm resources.

However, participation in soil conservation is itself influenced by a variety of socio-psychological and group level factors. One of the most important factors is the level of local understanding of the seriousness and causes of erosion and hence the nature of preventive action needed. Obviously, if a farmer perceives erosion as caused by a curse on the community, then sacrificing goats is going to be more relevant than making terraces.

The goal of soil conservation is ultimately to increase the farm productivity and population carrying capacity of a zone. Unless farmers grasp this linkage, and develop their own associations between family subsistence food requirements and conservation, then maintenance of structures will not compete successfully for resources with other farm activities. Thus, perception problems do not simply include environmental perceptions but the relation of terracing, for example, to manuring, fertilising, early ploughing, seed selection, etc. to increase yields.

A technical understanding of the effect of rain drops and runoff is also important to the perception of what structures are necessary and sufficient to halt erosion. If farmers perceive cutoff drains alone as sufficient, then the effectiveness of even these structures may be jeopardised. In this paper, we examine the local attitudes and perceptions in six locations of Machakos District which are relevant to a soil conservation programme and appropriate educational approaches.

DATA BASE FOR THE STUDY

There were two principal data collection techniques used in this study: a general survey and key informant interviews. The 310 respondents to the general survey were selected through a combination of stratified area sampling and random sampling. They were all members of soil conservation *mwethya* groups (self-help groups composed largely of women) operating in the locations of Kalama, Wamunyu, Kibauni, Masii, Mwala or Muthetheni in the Machakos area. Questions in the survey were focussed on the individual farmers, their attitudes towards conservation, general farm and conservation practices and other relevant socio-economic characteristics.

For each of fifteen mwethya groups, chosen both on the basis of level of group activity and ecological setting, five key informants were questioned. These informants were key persons in the mwethya group, either because they occupied an official leadership role or because they had a great deal of unofficial influence on their group. Key informant interviews attempted to assess the mwethya groups as completely as possible in terms of leadership, group activities and the problems facing the groups. Only part of the data generated in this study is discussed in this paper, although we attempt to raise as many relevant issues as possible.

SPECIFIC TYPES OF PERCEPTIONS

How people perceive or understand their environment and how their perceptions are related to their actions - these questions are not fully understood by social psychologists. By perception we mean the appreciation of phenomena in one's environment and the development of cognition or mental images and evaluative criteria about them. Bateson (1942) argues that the human individual is endlessly simplifying, organising and generalising his own view of the total environment and constantly imposing his own constructions and meanings through his behaviour. Thus such 'meanings' or 'constructions' define an individual's attitudes to phenomena and determine his views and criteria for action. If we define perception as the sum of knowledge, understanding and attitudes, then the relationship between perception and action is determined by the degree to which such knowledge is used in decision-making. Thus we are concerned not only with what local people know - how they respond to environmental factors - but also with the degree to which this knowledge is an important factor in determining their soil conservation activities.

PERCEPTION OF THE CAUSES OF SOIL EROSION

Table 1. Perceptions of the causes of soil erosion (percentages).

Ploughing down slope	21
No terraces	34
Not cultivating deeply	25
Overstocking	5
Hand cultivation (no ploughing)	4
Other, e.g., destroying terraces, burning bushes, no crop rotation	11
	100
Total n (number of group members interviewed)	310

In the locations studied, casual observation would indicate that the most serious factors leading to soil erosion are overstocking, lack of conservation structures and destruction of vegetation, in that order. The most seriously affected regions are the grazing lands. The first response in Table 1 appears to be an echo of extension advice rather than actual observation, because one does not see anyone ploughing down slope in this area.

Table 2. Perceptions of the best way to combat soil erosion (percentages).

Terraces	44
Tools, machines	37
Unity of people	14
Other, e.g., training leaders, provision of grass, seeds, etc.	5
	100
Total n	310

Tables 1 and 2 indicate that people do not have very concrete perceptions of the causes of soil erosion. These tables show that the the solutions which have been put forward to stop erosion may in some cases be oversimplified. Provision of tools is certainly necessary for a good conservation programme, for example, but the strong, almost exclusive emphasis on terraces means that the majority of local people perceive soil conservation in a very limited way.

A review is also needed of the attitudes towards special problems of soil erosion, such as bare grassland areas. Also, more comprehensive education on causes of soil erosion is necessary. Knowledge deficiencies appear to be critical in the following areas:-

1. Causes of erosion. This includes soil exposure, the effects of rain drops and crater formation, runoff, wind erosion and the intensity of sheet erosion. In some areas we found small plants growing on islands of soil one foot above the general ground level for which farmers had no explanation.

2. Preventive measures. We found that most farmers feel that one method of conservation is sufficient. For example, farmers felt that cutoff drains were sufficient for the reclamation of bare grassland and there was no need to plant grass on bare ground. The need to see conservation as a carefully designed package programme is critical. For example on denuded ground, slowing the runoff of water is only a first step which must be followed

by planting grass, weeding pasture, controlling grazing, applying manure or fertiliser, fencing, etc. The design of carefully prepared training materials on these relationships is an important educational approach to the conservation programme.

Table 3. Perceptions of the reasons why grassland should be reclaimed (percentages).

Increase grazing land	40
Stop erosion	20
Bare land is useless	14
Land looks unpleasant	7
Bare land causes lack of water in the area	8
Others, e.g., bare grassland leads to gullies	
	100
Total n	310

The majority of the respondents felt that grassland should be reclaimed in order to increase grazing. Whereas on the face of it this is a valid response, i.e., to increase carrying capacity, we found that the older respondents most often gave this reason. Their concern appeared to be with decreasing herd size and greater livestock mortality from drought and starvation. These people are unlikely to participate willingly in a long-term pasture reclamation programme which may include keeping livestock out of certain denuded areas for long periods, since such measures would entail keeping smaller herds. The need for 'dramatic improvement' in pastures under any programme or for sending livestock to 'holding farms' was expressed by the majority of the respondents. They seem to feel that farmers could be assisted to buy cooperative farms which they would use as holding farms while they reclaimed their own pastures without losing their subsistence supply of milk or the petty cash obtained from selling or butchering the odd cull. Farmers were not keen to relate overgrazing to erosion, or even to define the factors leading to overgrazing such as overstocking or poor establishment of grass. Yet as stated earlier, this was perhaps the most serious conservation problem observed in most areas except Masii.

Gullies are a serious problem on sloping land in Kalama and Kilungu. In these areas, people have had favourable experience with sub-surface dams. In areas where slopes are not very steep and the flow of water is likely to be slow, sisal was mentioned as a solution. In fact sisal

Table 4. Perceptions on how bare grassland should be reclaimed (percentages).

Cutoffs[a]	53
Plant grass	26
Dig cutoffs	10
Plough the land	7
Other, e.g., plant trees, stop grazing	4
	100

a. 'Cutoffs' was a term used by the respondents to refer to various types of conservation structures.

might be able to establish itself in a gully. Tables 5 and 6 present the respondents' attitudes concerning gully reclamation in more detail.

Table 5. Perceptions of why gullies should be reclaimed (percentages).

Stop erosion	52
They consume all the good land	17
So people and animals will not break their legs	10
Water drains into them	8
Others, e.g., land will have a more attractive appearance	13
	100
Total n	310

Table 6. Perceptions of how gullies should be reclaimed (percentages).

Plant sisal	28
Construct sub-surface dams	23
Construct terraces	13
Fill with soil	8
Plant grass	8
Plant trees	4
Fill with stones	6
Others, e.g., fill with logs	10
	100
Total n	310

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The solution most frequently suggested to control gully erosion was the planting of sisal, which is not suitable for all types of gullies. Filling gullies with soil, grass, trees, etc. may be feasible for small gullies but is difficult with larger ones. An alternative solution, not mentioned by the people interviewed, may be to establish vegetation and build cutoffs on the areas above gullies to reduce the amount of water flowing into them. One factor not mentioned or implied in the responses is the relative merits of each method in relation to the resources available to local communities. We found that most communities do not have the resources to reclaim a gully of average size, about 10 feet wide by 5 feet deep, and most existing conservation structures are in areas without gullies. There is a need to assess the amount of land lost through gully erosion and to devise measures to reclaim it.

Table 7. Perceptions of why forests should be preserved (percentages).

Building materials for houses	40
Induces rain	26
Charcoal	7
Windbreak	7
Firewood	7
Others, e.g., trees hold soil, sale of trees brings money	13
	100

Last, we enquired about forest preservation. The preservation of forest growth was the only special conservation problem which none of the respondents seemed to recognise: 16 per cent said it was not necessary, and most of those who did support the protection of forests gave unsatisfactory reasons in terms of the aims of conservation. Rather than reasons relating to conservation, many people suggested saving forests merely as sources of charcoal and firewood.

We found evidence of a number of misconceptions about trees and rain, and some of them are propagated by government officers who encourage farmers to plant trees to increase the rainfall. It is generally believed that it rains less than it used to and this is sometimes attributed to cutting down trees. We can find no evidence for this. The history of Machakos District includes periods of drought and famine as well as periods of heavy rain, and there is no appreciable long-term trend. What has happened however is that cutting trees plus overgrazing has led to much faster runoff of water when it does rain, and this has been accentuated as the network of channels has proliferated. Thus streams and springs dry up much more quickly than in the past, giving the impression that rainfall has decreased. Planting trees may not bring more rain, but it may slow down runoff and encourage infiltration. This coupled with deep seepage, raises the water table and consequently improve the continous streamflows. However, much will depend on slope, soil depth, type of trees, etc.

ATTITUDES TO DESTOCKING

It was anticipated that respondents who have lost livestock might have different attitudes to destocking, and hence the zones and locations in the study area are compared in terms of the extent of livestock losses and the attitudes to destocking. Farmers were asked to indicate how many of their animals had died in the previous year. Tables 8 and 9 show the breakdown of these losses for large animals only, that is cows, oxen, heifers and bulls.

Table 8. Agricultural zones and cattle losses (percentages).

Zone	Mean Number of Live Animals[a]	Number of Deaths of Cows, Oxen, Heifers, Bulls							
		0	1	2-3	4-5	6-7	8-9	Totals N	Totals %
Masii, Wamunyu, Muthetheni	7.87	19	10	16	11	9	35	178	100
Lower Kalama and foot hills	5.06	-	14	19	3	-	65	74	101
Hilly Kalama	4.74	2	7	11	5	-	75	56	100
Total n[b]		34	32	48	25	16	153	308	

a. This was the mean number of animals per herd for each zone at the time of the survey.

b. n= number of animals.

Table 9. Locations and cattle losses (percentages).

Locations	Number of Deaths of Cows, Oxen, Heifers and Bulls						Total	
	None	One	2-3	4-5	6-7	8-9	N	%
Kalama	1	11	15	4	-	69	90	100
Mwala	10	2	18	8	4	57	49	99
Muthetheni	-	15	23	12	19	31	26	100
Wamunyu	12	12	20	16	14	26	50	100
Masii	42	13	6	9	4	26	53	100
Total n	34	32	48	25	16	153	308	

256

From both Tables 8 and 9, it is clear that losses differed depending upon zones and the locations. The hilly zone had the highest losses of livestock, and this can be compared with the low remaining number of live animals relative to other zones. For the locations, Kalama had the highest losses, closely followed by Mwala. Close to 70 per cent of the respondents in Kalama had lost 8 to 9 large animals over the previous dry season. Another area of relatively large losses was Kiliku in Kibauni Location.

Looking at the attitudes towards destocking as shown in Table 10, there is a significant variation according to location. The relationship between livestock losses and attitudes will be brought out more clearly in a later section of this paper.

Table 10. Locations and attitudes towards destocking (percentages).

Location	Would you Destock?		Total	
	Yes	No	N	%
Muthetheni	67	33	24	100
Masii	61	39	49	100
Kalama	60	40	108	100
Wamunyu	54	46	46	100
Mwala	52	48	42	100
Total n	158	111	269	

AN EVALUATION OF THE UTILITY OF LOCAL ATTITUDES AND PERCEPTIONS

It can be observed in the areas under study in Machakos District that soil erosion is a major problem and that particular practices and attitudes contribute to this problem. For one thing, certain widespread beliefs should be discouraged since they do not appear to support the most effective solutions to the soil erosion problem. For instance, 99 per cent of the people interviewed felt that sisal lines are useful in preventing erosion on grazing land. Yet in the areas studied, sisal does not seem to perform effectively in preventing soil erosion. After growing to a certain height the bottom leaves decay, leaving an empty space at the bottom. Soil is often eroded around and through the roots of the plant. People also use the dried leaves as firewood, and animals feed on sisal during time of drought. The base of the plant is in many areas from one-half to one-and a half feet above the surface of the soil. For land that is fairly level, planting sisal is not an adequate means of preventing erosion.

On the other hand, it would be useful to investigate further the potential usefulness of sisal in gully reclamation. It might be the case that if slopes are not very steep and water velocity is low, sisal can be established

Table 11. Solutions frequently suggested for various soil erosion problems.

Problem	Two of the Most Frequently[a] Suggested Solutions to the Problem	
Soil erosion	1. Terraces (44%)	2. Tools or machines (37%)
Bare grassland	1. 'Terraces'[b]	2. Plant grass (26%)
Gullies	1. Plant sisal (28%)	2. Sub-surface dams (23%)

a. This refers to the largest percentage.
b. Again, this refers to conservation structures in general such as cutoffs, etc. Cutoffs are basically the same as terraces, but with a much larger channel and ridge.

in gullies and will serve as an effection measure to prevent erosion. This practice is popular in all of the areas studied.

Digging cutoff drains entails another problem. People may perceive complementary soil conservation practices as mutually exclusive. In other words, if one practice is adopted, it may be believed that other practices are unnecessary. Half of the farmers who never dug cutoff drains gave as their reason for this the fact that they had constructed terraces. Having terraces, they felt that digging cutoff drains would be a duplication of effort. Farmers should be made to realise that many different strategies are needed to tackle the complex problem of erosion effectively.

Finally, there are potential difficulties when people give the desire for more firewood, or more wood for charcoal making or building, as the reason to conserve trees. If these are the main reasons for conserving trees, the people may merely be planning to cut down the trees at a later date.

Despite these few areas where it appears that people's attitudes should be changed, there are other areas where their attitudes are basically sound but need to be modified to some degree. Sub-surface dams made from stones and cement are one very effective method for reclaiming gully areas. They are much more practical than planting sisal, since they not only conserve soil but also store water.

One farmer in the Kikaso mwethya area has reclaimed a gully in a very unique way. He filled over 150 sacks with soil and put them in the gully until it was almost full. The remaining part was filled with soil, terraces were constructed and sisal was planted on the upper slope and banks and grass on the

terraces. Another farmer near Kyangala has established a good plantation of bananas in a gully area.

Soil conservation is rarely a once-for-all undertaking, but requires a continuing effort to maintain terrace banks, to raise the height of the lip (ridge) of terraces, to maintain the grass cover on the banks, and to remove silt from cutoff drains. Whatever assistance is given to farmers should encourage a continuing effort, rather than building a structure which is then neglected. People should be informed about the need for continued maintenance activities.

FACTORS INFLUENCING PERCEPTIONS

Perceptions can be influenced by the physical and social environment, by the individual's own experience, and by the opinions of other people who are important to him. In terms of the physical environment, the clearest example is the relationship between cattle losses and attitudes towards destocking. As shown in Table 12, more than half of those who had lost no cattle were against destocking, while even the loss of one animal alters the proportion to 71 per cent in favour of destocking. Of course those who have lost large numbers of animals often have so few left that they are unwilling to consider destocking as destocking is actually unnecessary. This shows that particular attitudes can be drastically affected by changes in the environment, such as severe animal losses in a drought-stricken area.

Table 12. Cattle losses and attitudes towards destocking (percentages).

Number of Deaths of Cows, Oxen, Heifers and Bulls	Would you Destock?		Total	
	Yes	No	N	%
0	47	53	30	100
1	71	29	31	100
2-3	69	39	44	100
4-5	55	45	23	100
6-7	74	26	15	100
8-9	58	42	124	100
Total n	157	110	267	

Those who have had the heaviest losses usually have the smallest number of stock at present. It is logical that they tend to be less in favour of destocking, as shown in Table 12. It would be sensible to push for destocking programmes in areas where losses have occurred but have not been extremely high.

In addition, certain ecological factors may have been in existence for a long time, and are not undergoing change at present. For instance, in one very rocky part of the country people joke that God created all the other parts of the land on the first six days and then on the seventh day threw down hi bag, which had only stones. People seem to feel that the land in such an area has been poor for a long time and hence the situation must be accepted. In general, long established ecological conditions are often the only major factors affecting an individual's idea of the usefulness of the soil and the relevance (or irrelevance) of his own efforts.

The social environment primarily refers to social groups such as soil conservation groups, which attempt to fight soil erosion collectively. Although the groups are effective in convincing people that soil and water conservation is necessary, their influence on the perception of remedies is sometimes limited by the leaders' limited technical knowledge.

It is instructive to review the projects mentioned as high priority by key informants from these mwethya groups. After construction of terraces, the only other soil and water conservation activity mentioned is dam construction. This indicates that the perception of conservation is limited at the group level to a few activities. The perceptions of these groups will then influence individual farmers to perceive conservation in this limited way.

Table 13. Other projects of high priority (percentages mentioning).

1.	Constructing dams	37
2.	Building schools	29
3.	Constructing cattle dips	6
4.	Constructing health centres	8
5.	Constructing roads	5
6.	Starting marketing or production cooperatives	8
7.	Building houses for members	8
	Total	101
	Number of key informants responding	60

As mentioned, the indivual's own experiences and personal characteristics can also affect his attitudes and practices. The most relevant experiences are those connected with general farm practices. Farmers who have adopted agricultural innovations are more likely to feel that the individual farmer can

REASONS FOR PRACTISING SOIL CONSERVATION AND A TECHNICAL DISCUSSION OF CONSERVATION PRACTICES

Given these general trends, it is necessary to discuss the rationale behind people's adoption of conservation practices. In addition, we include a discussion of the technical aspects of soil conservation and related problems.

Table 20. Major reasons for practicing or not practicing specific soil conservation measures.

(1) Began Terracing Cultivated Land

Why doing?	Why discontinued	Why, if never?
a. To prevent erosion (91%)		
b. To stop water from running through the farm (5%)		
(N = 310)		

(2) Began Deep Ploughing

Why doing?	Why discontinued?	Why, if never?
a. To soften the soil (22%)		a. Lack of good tools (50%)
b. To trap water (17%)		b. No oxen (39%)
c. To get more [illegible] for crops (13%)		(N = 28)
(N = [illegible])		

(3) Used Cover on Terrace Banks

Why doing?	Why discontinued?	Why, if never?
a. To hold soil on terrace banks (58%)	a. Uprooted during road construction (100%)	a. Lack of grass seeds or money (48%)
b. To prevent erosion (20%)	(N = 2)	b. I intend to do so (13%)
c. To feed cattle (10%)		c. They grow Naturally (12%)
(N = 220)		(N = 75)

Why doing?	Why discontinued?	Why, if never?
a. For building (33%)		a. Lack of trees to plant (25%)
(N = 220)		b. There are enough trees (20%)
		(N = 79)

(5) Began Ridging

Why doing?	Why discontinued?	Why, if never?
a. To trap water in the farm (73%)	a. No axes (100%)	a. Don't know the technique (32%)
b. To prevent soil erosion (11%)	(N = 4)	b. Lack of material (25%)
c. To lessen the speed of water (9%)		c. Never heard of it (12%)
(N = 186)		(N = 113)

(6) Began Fencing Pastures

Why doing?	Why discontinued?	Why, if never?
a. To protect grass from other cattle (63%)		a. Lack of material (25%)
b. To mark the boundary (18%)		b. Lack of time (15%)
c. To conserve feed for the cattle (12%)		c. Land is not adjudicated (10%)
(N = 165)		(N = 141)

(7) Began Destocking

Why doing?	Why discontinued?	Why, if never?
a. To have enough grass (18%)	a. They are few (60%)	a. The animals are few enough (60%)
b. To match the size of my land (16%)	b. The grass is enough (20%)	b. No cattle (33%)
c. To prevent erosion (15%)		
(N = 143)	(N = 5)	(N = 160)

Table 16. The relationship between farm innovations and soil conservation practises.

Farm Innovation (Ranks)	Conservation Practices (Ranks) 0 - 6	7 - 12	13 - 20	Totals in Innovation Ranks
0 - 6	12	2	1	15
7 - 12	26	21	5	52
13 - 18	28	90	16	134
19 - 24	11	63	26	100
25 - 30	--	3	2	5
Totals in Conservation Ranks	77	179	50	306

Note: gamma statistic = 0.56

these attitudes. Table 17 illustrates a correlation between age and perceptions of why grassland should be reclaimed. In some cases, the older respondents tend to support conservation measures for reasons that would tend to increase erosion in the long run. Respondents over 30 years old are more likely to support the reclamation of grassland in order to increase grazing land which implies a long-term commitment to keeping large herds of livestock.

Table 17 Reasons for reclaiming grassland according to age groups.

Age Group	Reasons why Grassland Should be Reclaimed (%) To Increase Grazing Land	To Stop Erosion	Land looks Unpleasant	Other	Total (%)	N
Under 30	24	31	2	43	100	43
30-39	42	20	8	30	100	83
40-49	39	22	10	29	100	88
50+	35	13	4	48	100	93
						307

Finally farmers may acquire information and attitudes from other people who are influencial. The persons seen as having knowledge and experience and with whom the respondents feel they can communicate easily are likely to determine their perceptions more strongly than all other factors combined. We were interested in determining the sources of information about conservation and began by investigating the level of contact with extension officers.

Table 18. Agricultural zones and extension visits (percentages).

Zone	Times Visited by Extension Agent in Previous Year: Never	1-2	3-4	Over 4	Total N	%
Masii, Wamunyu, Muthetheni	76	14	6	3	174	99
Lower Kalama and Foothills	80	14	4	1	70	99
Hilly Kalama	91	7	2	-	57	100
Total N	241	39	15	6	301	
%	80	13	5	2	100	

Table 19. Agricultural zones and attendance at farmer training centre courses (percentages).

Zone	Ever Attended F.T.C.? Yes	No	Total N	%
Masii, Wamunyu, Muthetheni	21	79	178	100
Lower Kalama and Foothills	12	88	73	100
Hilly Kalama	5	95	57	100
Total N	49	259	308	
%	16	84	100	

From Tables 18 and 19 it is clear that roughly 80 per cent of the respondents had no exposure to formal agricultural advice or instruction. Some 36 per cent of all respondents said they learned about soil conservation from friends and relatives, 12 per cent from the mwethya group and 23 per cent said they have never learned from anyone. Friends and relatives seem to exercise the major influence on local conservation knowledge and practises.

Of those who were exposed to extension services, over half said they were told to construct terraces, only 2 per cent were told to plant grass and 4 per cent to construct dams. Of those who attended courses at Farmer Training Centres, 24 per cent reported receiving instruction on soil conservation, 5 per cent on tree conservation, 20 per cent on planting Katumani maize, and the rest reported courses on cattle keeping, the care of poultry, etc. These responses seem to indicate a need for broader education programmes in the area of soil

play a positive role in increasing farm productivity. To the extent that they see soil conservation as another way of ensuring this productivity, they will also adopt conservation practices.

Tables 14, 15 and 16 show how farm practises may relate to conservation practises. The first two tables are Guttman scales of general farm innovations and soil conservation practises. The percentages refer to the proportions of respondents engaged in particular practises. Scale steps are then simply the ranking of the practises according to these percentages.

Table 14. Farm innovations.

Scale Step	Innovation	Percentage of Sample Group Members Adopting
1	Began planting Katumani maize	99
2	Began planting crops in rows	97
3.	Began ploughing land by tractor or ox plough	97
4	Began using farmyard manure Began crop spacing	96 -
5	Began early planting	93
6	Began seed selection	90
7	Began bush clearing	84
8	Began cattle dipping	80
9	Began crop rotation	76
10	Began frequent weeding	71
11	Planted fruit trees	60
12	Began seed dressing	48
13	Planted cassava as famine reserve	41
14	Farm surveyed	37
15	Began thinning and pruning	30
16	Began using compost manure	20
17	Began using casual labour	10
18	Began spraying and dusting crops	6
19	Planted cotton	4
20	Planted green grams	2
21	Opened savings account Keeps farm records	0.6 -
22	Installed water on farm Feeds cattle with purchased food	0.3 -
Number in sample		310
Coefficient of Reproducibility		

Table 15. Farm conservation practices.

Scale Step	Practice	Percentage of Sample Group Members Adopting
1	Began terracing cultivated land	100
2	Began contour ploughing	99
3	Used grass cover on terraces	90
4	Began conserving trees	82
5	Began ridging before planting	70
6	Began fencing pasture	58
7	Began destocking	44
8	Began planting hedges as windbreak	30
9	Began improving grass pastures	24
10	Built contour straw heaps	15
11	Planted grass strips between crop areas	10
12	Dug cutoff on cultivated land	5
13	Began keeping river banks for pasture	4
14	Began mulching	2
15	Began constructing dams on farm	2
Number in Sample		306
Coefficient of Reproducibility		0.88

Table 16 shows the relationship between the ranking of individual respondents on the two scales. In this case, each respondent was ranked relative to the other respondents in terms of the number of practises adopted. This means that the lower ranks represent those individuals who had adopted very few practises, while the higher ranks (for instance, 25 - 30 for farm innovations) represent those who had adopted many of the practises. In this table, a respondent's rank on one scale is compared with her or his rank on the other scale.

Most of the respondents - 90 - rank in the middle of both scales. Smaller numbers rank in the lowest group on both scales (12) or the highest group on both scales (2). The gramma statistic shows a positive relationship between the level of farm innovations and conservation practises, indicating that the respondents who are more innovative tend also to adopt more soil conservation techniques.

The positive correlation between group members who have adopted farming innovations and those who practise soil conservation suggests that there is a relationship between attitudes toward innovation and conservation efforts. Personal characteristics such as age, sex and level of education also influence

( ) Planted Grass Strips Between Crop Areas

Why doing?

a. For feeding cattle in the dry season (74%)
b. To reduce erosion (12%)
c. To increase soil fertility (9%)

(N = 54)

Why discontinued?

a. Because of drought (100%)

(N = 4)

Why, if never?

a. The land area is too small (34%)
b. Lack of grass seeds (15%)
c. All the land is cultivated (14%)

(N = 213)

( ) Dug Furrows on Cultivated Land

Why doing?

a. To direct water away from land (28%)
b. To prevent erosion (22%)
c. To trap water (20%)

(N = 200)

Why discontinued?

a. Lack of tools (100%)

(N = 6)

Why, if never?

a. I prefer terraces (30%)
b. I intend to in the future (19%)
c. The terraces are enough (17%)

(N = 104)

(1) Began Keeping River Bank for Pasture

Why doing?

a. To feed animals (96%)
b. To sell the grass (2%)

(N = 57)

Why discontinued?

Why, if never?

a. Not near the river (67%)
b. River is dry and stony (12%)

(N = 243)

(11) Began Mulching

Why doing?

a. To retain moisture (52%)
b. to protect terraces (26%)

(N = 19)

Why discontinued?

a. Lack of rainfall (100%)

(N = 2)

Why, if never?

a. Lack of plant material (68%)
b. Don't know the technique (13%)

(N = 276)

(12) Began Constructing Dams on the Farm

Why doing?

a. To get water for domestic use (48%)
b. To increase amount of water (35%)

(N = 23)

Why discontinued?

Why, if never?

a. Lack of tools (35%)
b. Lack of money (34%)
c. No river nearby (13%)

(N = 246)

(13) Planted Trees

Why doing?

a. For wood to build houses (36%)
b. To break strong winds (12%)
c. To attract rainfall (12%)

(N = 138)

Why discontinued?

a. They dried up when planted (100%)

Why, if never?

a. Lack of rain (44%)
b. There are a lot of trees (14%)
c. Lack of money (10%)
d. 'Ants' problem (90%)

(N = 124)

(14) Dug furrows on Uncultivated Land

Why doing?

a. To prevent erosion (47%)
b. To divert water to cultivate land (17%)
c. Because water may carry grass (15%)

(N = 59)

Why discontinued?

a. Lack of tools (100%)

(N = 2)

Why, if never?

a. No tools or poor tools (21%)
b. I want to do the cultivated land first (13%)
c. Lack of time (10%)

(N = 245)

(15) Brought Water to the Land

Why doing?

a. For domestic use (90%)
b. For irrigation (10%)

(N = 10)

Why discontinued?

Why, if never?

a. Lack of money (58%)
b. Lack of water (17%)
c. Lack of water pipes (7%)

(n = 298)

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Note to Table 20.

The major reasons are those reasons which were given by the largest percentage of the respondents. These percentages will not equal 100% since not all reasons are included in the table. The N refers to the total number of respondents who said they were presently doing, or were not now doing, or never done a certain practice. If some respondents did not reply to specific questions the total of all N's will not equal 310.

Several points emerge from Table 20. For one thing, the reasons state for adopting specific conservation practises are often not actually related to conservation. For example, if trees are only preserved for later use as firewood or building material, they may not be allowed to remain long enough to achieve conservation goals. The terracing of cultivated land is the one exceptional practise where almost all the respondents mentioned prevention of erosion as the basis for adoption. From observations in the field, it seems that most cultivated land is protected against erosion by cutoffs and bench terraces with the exceptions of Kilungu and Mukaa Locations.

Of all the terraces examined, the majority can be classified as bench terraces. Most of these have been constructed by throwing soil uphill (the fanya juu method). In this way banks are formed which are often nearly vertical and between which the slope of the ground is reduced. The extent to which the original slope of the cultivated land is reduced by terracing varies greatly. On a number of farms the land between the banks is approximately level but on the majority it is still sloping forward to varying degrees and runoff accumulates at the front edge of the bench. Where there is a substantial lip (ridge) along the front edge of the bench and where the bank and lip are stabilised with grass, any run-off accumulating at the front is retained and eventuall infiltrates or evaporates. However, on a number of farms the lip is inadequate and the grass cover poor or even non existent. In these circumstances, it is inevitable that runoff passes from one bench to the next and in so doing carries with it some of the soil which has been painstakingly thrown up to form the bank.

A second important point is that the reasons given for discontinuing a conservation practise or never adopting it may indicate to government planners what would be the most useful approaches for overcoming these constraints. For example, most respondents understood that deep contour ploughing is usefull because it loosens the soil. However, half of those who had never ploughed deep did not have the necessary tools, and another 39 per cent lacked oxen. Similarly the reasons given for not fencing pastures include a lack of material and the fact that the land has not yet been adjudicated. For planting vegetation strips between crop areas and for mulching, the lack of material is cited as the major reason for non-adoption. Lack of tools is given as the major reason for not constructing dams and not digging furrows on uncultivated land. These responses indicate that in many cases non-adoption is due to a lack of resources, rather than to attitudinal factors. In other cases, the major constraint seems to be a lack of technical knowledge of how to carry out certain practises.

The use of Makarikari grass on terrace banks has been widespread but is not always satisfactory. Alternatives need to be evaluated in different ecological zones. In this case then, the practice itself needs to be slightly modified in terms of the type of vegetative cover used. Lack of planting material is the major reason for never adopting this practice and this again is connected to the economic resources of the individual farmer.

Conserving trees is a critical issue for government planners. About 10 per cent of the people interviewed stated that trees attract rain. To what extent is this belief scientifically valid? Trees are often conserved so that they may later be used for firewood and building material, which indicates that they may only be preserved in the short run. The reasons given for planting trees are almost the same as those given for conserving them. However, in the case of tree planting, both non-adoption and discontinuation are related to lack of rain and the 'ants' problem, as well as to a lack of seedlings.

At this point, we should clarify the 'ants' problem, since it inhibits the adoption of several other soil conservation practises. When water is scarce in an area, these 'ants' - which are actually termites - eat all the grass and loose dry matter. At Kiatuni, they are reported to have swept through one mile on either side of the Syuuni River, creating a near desert. Then they tend to move on to greener areas.

Basically, terrace banks, crops and overgrazed land are threatened by these termites. The respondents complained that ants are a major threat to terrace banks as they build nests below the upturned soil and eat any grass that is planted. They kill young crops such as maize, and overgrazed land also appears susceptible to attack. This problem may have become more critical in recent years because of the removal of the termites' natural enemies such as ant bears and black and brown ants. From our field observations we concluded that most areas of bare land in Kalama and Kibauni are the result of this termite infestation, and they may be as serious a problem here as army worms in other areas.

Many people (44 per cent) did not ridge their fields because they do not know about this technique. A number of respondents also did not know about the benefits of planting hedges as windbreaks. Where hedges had been planted but the practise later discontinued, the termite problem was blamed. Of those

who had never fenced their pastures, 10 per cent gave as their reason the fact that the land was not adjudicated. A larger proportion of the total sample - 25 per cent - in fact had not had their land adjudicated. While some saw non-adjudication as a barrier to conservation practises, others did not.

Most respondents have never made straw heaps (trash lines) on the contours of their fields because the straw is stored for cattle feed. River banks are kept for pasture and grass strips are planted between crop areas primarily for the purpose of feeding cattle. Respondents were also asked whether they had ever planted crop land in grass. Of those who had, 37 per cent planted star grass, 26 per cent Napier grass, 4 per cent Rhodes grass and the rest planted other types of grass.

Grazing land is poorly protected relative to cultivated land. After a period of heavy rain there are good crops on many farms, but the grazing land which might be expected to have a thick cover of grass is frequently bare or nearly bare. Recovery of grass after the recent prolonged dry spell has been relatively slow and erosion appears to be continuing rapidly. The only exceptions are where the owner has protected his grazing land and allowed it to recover. The combination of a long dry spell, heavy grazing and termite activity has undoubtedly been responsible for killing many of the grass plants. As the compacted surface of the ground provides a poor environment for seedlings to become established, some intervention is needed to re-establish a sward. Some of the effort at present devoted to digging cutoffs on grazing land might achieve results of greater value if it were devoted to restoring grass sward.

Hartley, B.J. 1938. An indigenous system of soil protection. East African Agricultural Journal 4:63-66.

An Indigenous System of Soil Protection*

By B. J. HARTLEY, *M.B.E., N.D.A., A.I.C.T.A., Agricultural Officer, Department of Agriculture, Tanganyika Territory*

The Erok people of Mbulu District inhabit the mountainous country which rises between the Great Rift Valley and the Yaida and Eyassi depressions. The origin of the tribe is obscure. S. B. Leakey (*Kenya, Land of Contrasts and Problems*), has suggested that they may be the descendants of neolithic people of the type inhabiting the City of Engaruka, whence Masai history records the Mbulu District tribes fled. Whatever their origin, these people have an intelligence which appears to be above the type shown by the ordinary Bantu peoples.

Under pressure from the Masai on their northern flank and with treacherous neighbours in the Tatoga peoples, the timid Erok were, for some time before the advent of the European, confined to a limited area which they had carved out of the forest clad mountains. Like other tribes in similar circumstances, such as the Wamatengo and Wakara, they evolved a system of soil conservation.

The slopes under cultivation would deter almost any but those who find it necessary to eke out a living there, but a favourable rainfall and a not infertile soil compensate for the considerable labour required to a farm on the Erok system.

Land for cultivation is whenever possible selected in the steep and narrow valleys. The fields are of small size, generally about one quarter of an acre and are made to occupy a single "terrace". These terraces are in the early stages protected by a storm drain above the field and cultivation is designed to work the soil away from the slope until it is level. Owing to the steepness of the slopes and the adjustment of a field to each terrace, the vertical interval between the terrace edges is considerable; for this reason a perfectly level terrace is only seen in favourable situations. The climate provides an all-the-year-round growing season and enables the cultivator to protect his terrace edges with grass and crops; as a result the usual deterioration of the terrace edge so commonly seen in drier situations does not occur.

The formation of a terrace is a gradual process. After the construction of a storm drain, followed by the pulling down of soil from a face say three feet deep, and the provision of a Kikuyu grass verge on the edge of the terrace, cultivation will proceed.

Old fallow land or new land is deeply cultivated with a long digging pole which turns over the sod, leaving a very deep broken surface to weather in the cold season. With the advent of the true short rains season and higher temperatures this land will be contour planted between small ridges with (say) maize, while a strip of pumpkins is established on the lower side of the "terrace" to afford additional protection. At hoeing time the ridges are commonly reinforced according to the season and the amount of rubbish which may have been buried. In some cases the ridges may be split back to earth-up crops, but still naturally retain their soil and water conserving principle.

Important practices affecting the terraces occur when the next planting takes place. Assuming that a short rains crop has been removed in May, the cultivator's next work is to chop out the

*Previously appeared in Vol. III, No. 4, *without* illustrations.

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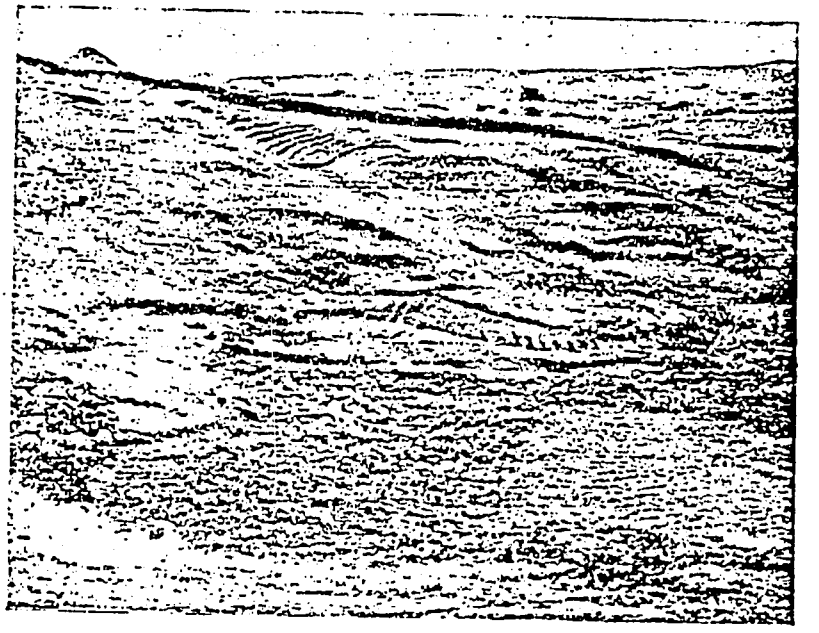
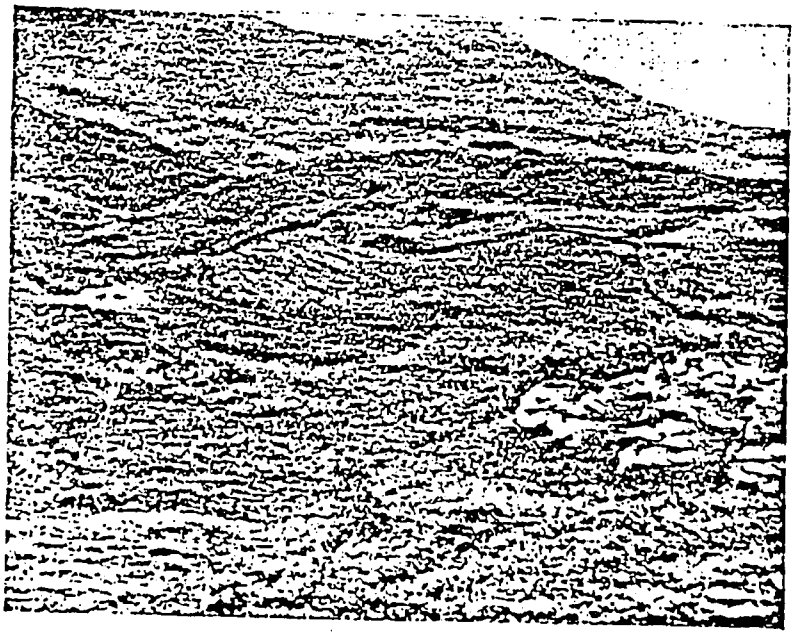


Fields in the Kainam area, with crops planted in contour lines of field terraces



View from below the edge of a terrace showing on the right a strip of pumpkins planted just above the Kikuyu grass bank

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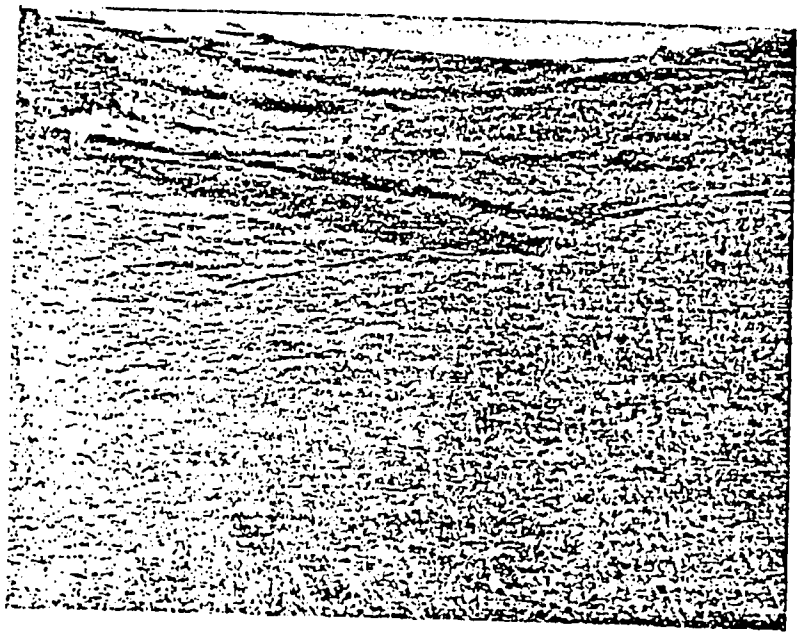
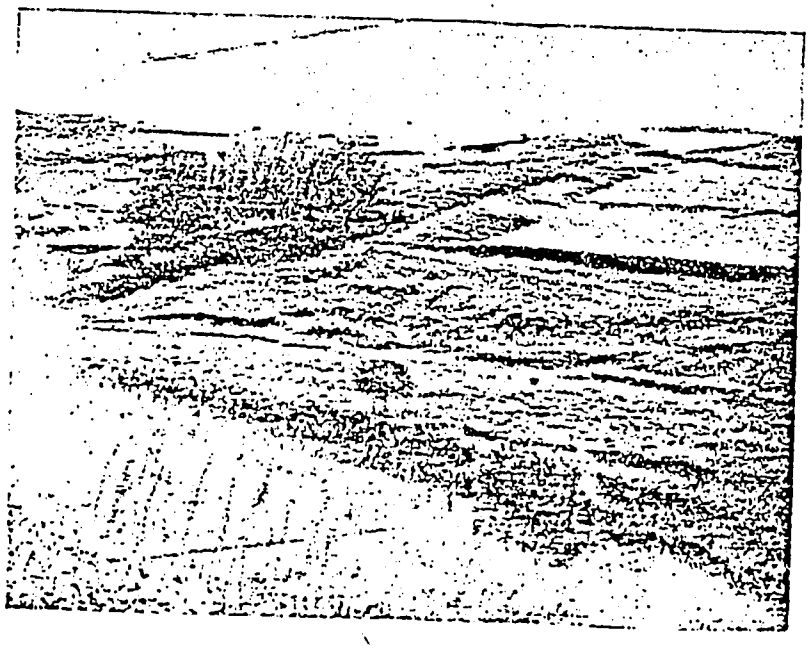


A field terrace, showing thatched ground



An Iraqw field landscape

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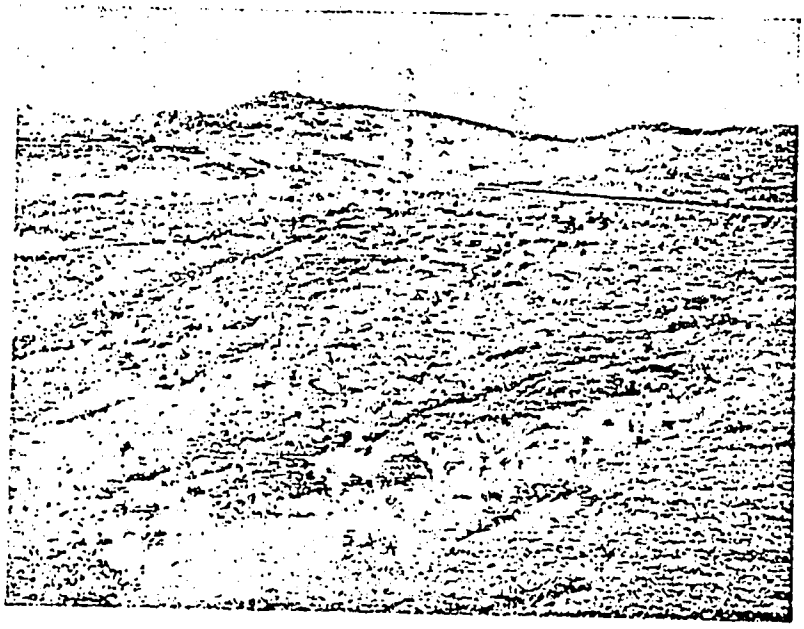
stover and lay it evenly over the field. The value of this thatch in conserving moisture is understood by the Erok cultivator, who could well do with such stover as forage for cattle from his overstocked grazing. When cultivation takes place this stover is drawn into lines starting at the lower side of the terrace, then ridged over and the seed planted at once between the ridges; in the process of ridging the soil is pulled downhill and gradually season by season the terrace is formed.

well repay investigation elsewhere under varying conditions of rainfall.

Soil movement within the plot under this system is reduced to a minimum while at the same time loss from the terrace is adequately controlled. Wash from land surrounding the cultivated terrace is, in the old Erok country, of little danger on account of the presence of a fair grass cover, while depth of soil assists in the formation of the terraces, many of which have faces twelve feet deep.



Fields planted without protection on the Aitcho escarpment—an area formerly occupied by pastoral tribes only, but now in process of settlement by Iraqw cultivators

To those experienced in the dangers of even green manuring under dry conditions it seems remarkable that a heavy stand of dry stover can be so disposed of after the heavy rains without any noticeable effect on the following crop. Too often trash and weed growth is burned or eaten off in the field owing to difficulties of disposal in the soil; this Erok method of sowing a listed crop between the ridges carrying rotting crop residues is a development which would

The problem which now confronts Government is the introduction of anti-soil erosion measures to the members of the tribe who have moved from their ancestral fields to the drier, less mountainous areas. Here, overstocking, flat cultivation and rainfall more of the unstable type found in semi-arid areas, provide ideal conditions for wide-scale soil damage. The Erok, no longer afraid, is content to cultivate and move on; he has become a miner instead of a farmer.

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Okigbo, B.N. 1977. Farming systems and soil erosion in West Africa. in Soil conservation and management systems in the humid tropics, ed. D.J. Greenland and R. Lal, 151-61. Chichester: John Wiley and Sons.

Farming Systems and Soil Erosion in West Africa

B. N. OKIGBO

5.2.1. EROSION HAZARD IN WEST AFRICA

Adverse effects of erosion on soils, vegetation, ecology and human welfare have received the attention of various authors (Grove, 1951, 1952; Guillaûme, 1951; Jurion, 1956; Langdale-Brown, 1968; Middleton, 1952; Strahler, 1956; FAO, 1960, 1965; Fournier, 1967; Floyd, 1969; Ahn, 1970), and space and relevance of this to the topic under consideration does not permit a detailed treatment here. Insofar as erosion causes general soil degradation and loss of soil fertility and productivity, it constitutes a hazard to farming. Equally, farming is one of the major human activities which when not properly conducted constitutes a hazard to the soil. Thus, according to FAO (1960, 1965), farming is most hazardous in relation to the extent of damage and potential damage due to erosion in tropical, mountainous and hilly regions of the world where heavy rains are common. In these areas, it is difficult to control water erosion on sloping land. The areas in Africa where serious damage has been observed include Swaziland, Lesotho, Botswana, East Africa, heavily populated areas of Ruwanda and Burundi, southeastern and Bauchi plateau areas of Nigeria, parts of northern Ghana and hilly areas of Sierra Leone.

In general, in West Africa as elsewhere in the tropics, water erosion, especially of the sheet erosion type, is more widespread in unprotected croplands and overgrazed pastures than wind erosion. This kind of erosion is more serious than is usually appreciated because it slowly and gradually depletes the soil qualitatively and quantitatively and sets the stage for more spectacular gully erosion and floods (FAO, 1965). Lal (1973) related erosion hazard to rainfall distribution in West Africa and outlined the parts of West Africa that are particularly susceptible to rainfall erosion. The areas concerned included all of Zaire, Gabon, the Cameroun Republic, Nigeria, Ghana, Dahomey, Ivory Coast, Liberia and Sierra Leone, with a northern zone consisting of areas with average annual rainfall of less than 1000 mm and a southern zone consisting of areas with more than 1000 mm annual rainfall, that are susceptible to rainfall erosion when the vegetation cover is removed.

Observations under experimental conditions in various parts of West Africa also support the view that sheet and to some extent rill erosion are serious in unprotected soil (Mouttapa, 1973; Lal, 1973). Estimates of quantities of soil removed by erosion from soils under different slopes and surface cover in Ouagadougou (Upper Volta), Sefa (Senegal), Bouake and Abidjan (Ivory Coast) are presented in Table 5.5.

A more impressive manifestation of the seriousness of the erosion problem in parts of West Africa is the spectacular and disastrous gullies which have destroyed vast areas of land in the Nanka, Agulu, Oko and Enugu areas of the Anambra State and Shendam and western Pankshin areas of the Plateau State in Nigeria (Grove, 1951, 1952; Floyd, 1969; Udo, 1970; Ofomata, 1964) (Plate 22). Recently (Anon, 1974a) the erosion damage in East Central State was estimated as causing losses of over 13 million tonnes of soil, or amounting to over ₦300 million annually, with the gullies extending to depths of over 120 m and up to 2 km wide in places.

5.2.2 EROSION HAZARD AND FARMING SYSTEMS IN WEST AFRICA

The current concern about drought, erosion and soil conservation in various parts of Africa is only an aspect of a long-standing concern. The gullied hillsides and badlands of the Anambra State of Nigeria, already referred to above, were noted by European visitors as early as 1913 (Grové, 1951). An enquiry concerning the possible drying up of land in the then French West Africa was reported by Hubert in *Bulletin de l'IFAN* in 1917 (Anon, 1957). The Inter-African Information Bureau for Soil Conservation and Land Utilization which started the journal *African Soils* was set up in 1948 with the objectives of (i) providing a medium for exchange of information among those interested in research on soils, erosion control and soil conservation, in addition to (ii) promoting the adoption of sound agricultural methods of soil conservation. In fact, it would appear that, as indicated in reviews of research and related activities on erosion, soil conservation and land utilization in the then British Colonial Africa (Greene, 1951), the Intertropical zones of the French Union (Guillaume, 1951), the Belgian Congo (Jurion, 1951), the Union of South Africa (Adler, 1951) and Africa and Madagascar (Fournier, 1967), there was perhaps greater concern about these problems then than there is today. The early reviews and reports of several missions sent out to parts of Africa, on soil conservation and erosion control, emphasized the importance of human activities, especially those associated with past and present farming systems, in the evolution of present landscapes and soil degradation due to erosion (Guillaume, 1951; Porteres, 1952a, b; Guilloteau, 1955).

Of the various factors which determine the intensity and seriousness of erosion, vegetation cover, land use and farming are to a large extent dependent on human activities. The human activities which affect erosion are listed in Table 5.6. Each

of the farming systems in Table 5.7 usually involves one or more of these activities. The ways in which they influence erosion are considered below.

Table 5.5. Runoff and erosion under various covers of vegetation in parts of West Africa. Source: Charreau (1972) in Mouttapa (1973)

Locality	Study period	% slope	Average annual rainfall (mm)	Annual runoff, %			Erosion (tonnes/ha)		
				Forest	Crop	Barren soil	Forest	Crop	Barren soil
Ouagadougou (Upper Volta)	1967–70	0·5	850	2·5	2–32	40–60	0·1	0·6–0·8	10–20
Sefa (Senegal)	1954–68	1·2	1300	1·0	21·2	39·5	0·2	7·3	21·3
Bouake (Ivory Coast)	1960–70	4·0	1200	0·3	0·1–26	15–30	0·1	[illegible]–26	18–30
Abidjan (Ivory Coast)	1965–70	7·0	2100	0·1	0·5–20	38	0·03	0·1–90	108–170

Table 5.6. Farm practices and operations determining the extent of erosion hazard

1. Bush-clearing (slashing, pruning, burning, mechanical and chemical methods)
2. Burning of vegetation for ceremonial purposes, flushing out small game, encouraging green bite for livestock, etc.
3. Preplanting cultivations (flat, ridge, mounds, ploughing)
4. Fallowing and mulching
5. Manuring and fertilization
6. Weeding
7. Cropping systems (row, sole, intercropping and pasturing)
8. Logging and related forestry activities
9. Harvesting and grazing
10. Restriction of livestock
11. Farm and household refuse disposal
12. Footpaths to farms, water supplies and springs, and markets
13. Compound development and maintenance

Table 5.7. General classification of farming systems found in West Africa. Adapted with modifications from Greenland (1973), Floyd (1969), Morgan and Pugh (1969), and Laut (1971)

A. Traditional and transitional farming systems
   1. Shifting cultivation (phase I including nomadic herding), $L > 10$
   2. Bush-fallowing or land rotation (shifting cultivation phase II), L 5–7
   3. Rudimentary sedentary agriculture (shifting cultivation phase III), L 3–5
   4. Compound farming and intensive subsistence agriculture (shifting cultivation phase IV), $L < 2$
   5. Terrace farming and floodland agriculture, $L \leq 1$
B. Modern farming systems and their local adaptations
   1. Mixed farming
   2. Livestock ranching
   3. Intensive livestock production (poultry, pig production and dairying)
   4. Large-scale plantations
      (a) large-scale food and arable crop farms
      (b) Irrigation projects
      (c) Large-scale tree crop plantations
   5. Specialized horticulture
      (a) Fruit trees and/or ornamentals
      (b) Market gardening

L = land use factor of Allan (Greenland, 1973) = $(C + F)/C$ where C = cropping period in years and F = fallow period in years

1. *Bush-clearing.* This is the most important and first operation carried out to facilitate cultivations and planting. In traditional farming systems hand-clearing methods are generally used. Most of the shrubs are cut at heights of about a metre from the ground, but where the stumps are to be used for staking they are cut at heights of 2–3 m. Usually very large trees are left standing, but where they are very close together the branches are sometimes heavily pruned down. The clearing is usually carried out in the dry season, and completed by burning the dried materials. The stumps are usually not dug out except when clearing to establish plantations, when the stumps close to the planting holes are usually dug out with picks. After two to three years when cropping is completed, the stumps sprout and regenerate and grow into secondary bush. In such situations no serious erosion occurs except during the short period between cultivations, planting and development of crops, which should provide some cover during the growing season.

Clearing for plantations may be carried out by hand where labour is cheap, but usually it may be accomplished by chemical and mechanical methods. In chemical clearing, ring-barking is done at convenient heights from the ground and chemicals such as sodium arsenite or 2,4,5-T are used to poison the plant (Webster and Wilson, 1966). Winches may also be used in clearing, but usually for large areas of thick forest almost all operations can usually be mechanized. Both the clearing of the undergrowth and the felling of trees may be done with a bulldozer. Heavy tractors could be employed in chain-clearing. For tree crop plantations, stumping is not necessary and all the plant materials are left to dry before burning. Some trees are selectively left to provide shade, but where annual

crops are to be grown, mechanical stumping, piling in windrows and root cutting may be carried out to facilitate mechanical cultivation. Unless carefully done, bulldozer piling, stumping and root cutting may result in serious disturbance of the soil surface, exposure of subsoil in places and destruction of soil structure by compaction. This kind of clearing often results in serious erosion leading to crop failure except where it is carefully carried out without disturbance of the surface soil and when the soil is not very wet.

2. *Burning of vegetation.* The cut and burn technique is the traditional method of bush-clearing in West Africa. Burning is also carried out for various reasons including flushing out of small game, ceremonial purposes or for fun, encouragement of 'green bite' or fresh uniform growth of fodder for livestock, and sometimes by accident (Grove 1951, 1952; Floyd, 1969). Burning may be advantageous in releasing nutrients to crops and other plants, and in the destruction of weed seeds, pathogens and pests. However, it causes nutrient losses through leaching and surface runoff, destruction of soil organic matter and structure, and destruction of fauna and flora, thereby disrupting the ecological balance which existed previously to an extent that makes restoration impossible. Sometimes valuable economic trees are destroyed by fire or exposed to secondary infection by pathogens. Burning *per se* is not altogether harmful, and controlled early burning of grasslands in the savannah areas is known to encourage tree growth and prevent late destructive burning (Vine, 1968). Frequent burning of forest and woodlands and constant clearing of bushes and felling of trees for fuel constitute practices which expose the soil to erosion.

3. *Preplanting cultivations.* In traditional farming systems, use of preplanting cultivations such as mounds, heaps, ridges and beds is widespread all over West Africa, especially on shallow soils and soils with high water-table during certain months of the year. Only on flat well-drained soils, alluvial plains and deep sandy loams is planting on the flat common. Heaps, mounds and ridges constructed on bare soil and sometimes running up and down the slope may expose the soil to serious erosion by concentrating the runoff so that it develops rills and gullies (Ahn, 1970; Floyd, 1969) (Plate 23). Tying of ridges (Plate 7), mounds and heaps, orienting them parallel to the contour, and mulching may reduce the danger of erosion (Plate 24).

4. *Fallowing.* Fallowing involving natural bush regrowth or planted fallows with selected plants is used in traditional agriculture to rest the soil, recycle nutrients and thereby restore the soil fertility for another cycle of cropping for one or more years. Fallows are most effective when they are long enough (7–20 years) to bring sufficient nutrients to the surface through leaf fall. When fallows are short, soil fertility is not adequately restored and subsequent crops and fallows fail to grow well and provide adequate cover for the soil. In modern agriculture, fallows of shorter duration may be planted with cover crops or green manure crops which serve to restore soil structure and add some organic matter to the soil.

5. *Manuring and fertilization.* Manuring is used in market gardening and to some extent in intensive farming in house compounds to maintain soil fertility

and productivity. Fertilizers are used for the same purpose in modern agriculture. Fertilizer use is not widespread in traditional agriculture and the little that is carried out is mostly restricted to cash or export crops rather than food crops. This is because fertilizers are expensive, frequently fail to give significant returns on land that has been in fallow for several years and, where they do give responses the food crops fail to command a sufficiently attractive price to make their use economic.

6. *Weeding.* Clean weeding exposes the soil to erosion unless the crop canopy is thick and close enough to protect the soil adequately. Weed suppression by mulching, by close cropping, and by suitably selected combinations of inter- and relay-cropping is much more desirable than other systems of weeding. Weeding by cultivation, even in plantation crops, especially where the soil is more erodible and on sloping land, may cause serious erosion (Plate 25).

7. *Cropping system.* In traditional agriculture, intercropping of arable crops and tree crops, some of which are planted and harvested at different times, ensures that the soil is usually protected (Plate 26) by a vegetative cover. Row crops such as maize, planted at wide spacing, expose the soil more to sheet erosion than non-row crops such as cowpeas, forage grasses and sweet potatoes, which are planted at closer spacing and provide adequate soil cover. While mono-cropping with maize can lead to severe erosion, this is much reduced if it is intercropped with cowpeas, cassava or sweet potatoes.

8. *Logging and forestry activities.* Tree-felling and logging with heavy equipment may result in compaction of the soil, especially along bush paths and roads. These form channels for gully erosion, which is most serious when they run straight up and down the slope.

9. *Grazing.* Natural and sown pastures can provide adequate cover to the soil, but overgrazing and overstocking of pastures may result in removal of cover. Added to this is the trampling by livestock, which converts their trails and footpaths to channels for gully erosion. Rotational grazing, controlled burning and good range management eliminate this potential erosion hazard.

10. *Restriction of livestock.* In traditional agriculture, livestock are often allowed to wander without restriction, so that they cause damage to crops and vegetation. Goats are notorious in this regard, and their activities may constitute a serious erosion hazard even in the humid tropics, especially if their numbers and movements are not controlled.

11. *Farm and household refuse.* These in many rural areas of West Africa constitute the manure and mulching material with which soil fertility is maintained. Their use as manure or mulch ensures continuous cultivation and ground cover in compound farms and gardens.

12. *Footpaths to farms, springs and markets.* Grove (1952) in his study of erosion and soil conservation in the Oko area of the Anambra State, Nigeria, indicated that footpaths, some of which run up and down the slope, and especially those leading to springs at the foot of the slope, farms, markets and compounds, amounted to about 5 per cent of the total area. These are always kept clean and bare, and so form the channels from which gully erosion develops.

In considering the association of farming systems with erosion hazard, each farming system may be considered as an agricultural enterprise satisfying specific objectives and involving various kinds of plant and/or animal inputs, together with the practices and operations with which it is managed in a given environmental setting. The various agricultural enterprises (farming systems) currently found in West Africa are listed in Table 5.7. They vary in their objectives, complexity, degree of sophistication and in the interaction of these practices with climatic and other environmental factors. The common practices often encountered in the farm business and in the farmer's environment are listed in Table 5.6. The extent to which these may affect erosion has been reviewed above. Normally, in any one situation man evolves his practices through centuries of experience so that they interact with the environment in such a way as to maintain a stable system of production. Any change in the social and economic factors that affect the farming system and its objectives is usually also associated with changes in practices and in the plant and animal inputs used in a given set of circumstances.

Under traditional natural fallow systems, where fallow periods are still long enough (up to 10 years or more) a reasonable balance can be maintained between fertility loss during cultivation and restoration under fallow. Erosion is minimized by ensuring that there is some cover during clearing, and by growing several crops together which protect the soil and minimize weeding. According to Grove (1952), before Western influence reached West Africa, ecological balance was maintained between people and their environment by controls of inter-tribal wars, famine, diseases, and farm practices and customs based on centuries of experience, adapted to maintain the relatively low populations.

In the last hundred years, various aspects of modernization, especially in terms of economic and demographic expansion, have brought about changes which have increased population pressure on the land and disrupted the balance of the traditional farming systems by seriously shortening the periods of fallow. Associated with this is the adoption of ill-advised and irrational agricultural practices which, while appropriate elsewhere, are incompatible with the environmental conditions and resource endowments of the traditional farmer of the humid tropics. The changes which have resulted in the present predicament include:

(i) Increasing population density and pressure on agricultural land and consequent increase in area of cultivated land, sometimes spreading to marginal areas that are unsuitable for farming with traditional techniques (Gourou, 1956).

(ii) More and more effort being devoted to increase food and export crop production to satisfy increased demand (Guillaume, 1951).

(iii) Overgrazing resulting from increased livestock populations and stocking rates (Guillaume, 1951; Grove, 1951).

(iv) Widespread deforestation resulting from shortening cycles of cropping and fallowing.

(v) Migration of peoples to areas where their traditional methods of

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agricultural production are unsuitable to the existing environmental conditions (Porteres, 1955; Guilloteau, 1955; Gourou, 1956).

(vi) Rate of development of agricultural techniques and organization of space not keeping pace with the increased rate of change from extensive farming techniques to more intensive systems (Gourou, 1956).

(vii) General economic development and improvement of means of communication which have brought West Africa closer to markets and drastically increased the pace of commercialization of agriculture (Gourou, 1956; Guillaume, 1951).

(viii) Increasing use of mechanical cultivation and large-scale farming (Obeng *et al.*, 1973).

Various classifications of agricultural or farming systems have been reported (Ramsey, 1968; Floyd, 1969; Morgan and Pugh, 1969; Laut, 1971; Greenland, 1973). The list in Table 5.7 is an adaptation from the various systems studied to suit the West African situation. It is by no means an exhaustive list. A brief summary of the characteristics of these farming systems and the extent of erosion hazard associated with them is presented below.

1. *Shifting cultivation (phase I including nomadic herding)*

(i) With the exception of nomadic herding, this system is not widespread in West Africa, but confined to a few isolated, semi-arid areas.

(ii) Non-sedentary, use of simple houses or movable tents, migration follows seasonal advance and retreat of rainfall.

(iii) An extensive system of agricultural production involving mainly livestock with sometimes (but very rarely) some cereals in favoured situations.

(iv) With improved veterinary services, increasing livestock numbers result in overstocking which is associated with increased erosion hazard, especially around drinking holes and watering places.

2. *Shifting cultivation (phase II) or bush-fallowing*

(i) Farms small in size often in isolated patches in secondary woodland or, rarely, virgin forest.

(ii) Homes usually permanent with small areas of more or less continuously cropped compound gardens around them, outlying farms change position frequently.

(iii) Cut and burn using simple tools practised at start of cultivation cycle.

(iv) A range of crops grown in mixed cropping systems which may include tree crops in the compound gardens.

(v) Some small numbers of livestock may be involved.

(iv) Length of bush fallows after each 2–3 years cropping period reasonably long (> 7 years) but may vary with population pressure.

(vii) Erosion hazard low except along footpaths, and in compounds.

3. *Rudimentary sedentary agriculture (shifting cultivation phase III)*

(i) Farm size smaller than in 2 above and less than 50 per cent of community land in fallows which rotate after each cropping cycle.

(ii) Cut and burn technique using simple tools followed.

(iii) Permanent settlement with compound gardens more intensively cultivated and associated with systems of outlying fields at varying distances from homestead.

(iv) Range of crops grown in mixed cropping systems and some livestock associated with them.

(v) Some small plots of protected or improved perennial cash crops often involved.

(vi) Planted, protected or natural bush fallows may be used in outlying fields with lengths of fallow 7–8 years or less.

(vii) Erosion hazard slightly increased especially with decreases in frequency and duration of fallow.

4. *Intensive sedentary agriculture or compound farming (shifting cultivation phase IV)*

(i) Farm size small, holdings fragmented.

(ii) Permanent settlements, simple tools and limited cut and burn techniques.

(iii) Compound farms more intensively and continuously cropped with fertility maintained with applications of household, farm and animal waste.

(iv) Crop mixtures including some perennial cash crops and fruit trees—a vegecultural complex with some livestock.

(v) Length of fallow in outlying farms often less than four years.

(vi) Erosion hazard high on slopes, footpaths and compounds.

5. *Terrace farming and floodplain agriculture*

Remnants of these according to Gourou (1956) and Morgan and Pugh (1969) are found in the Atacora Mountains, Bauchi Plateau, Mandara Mountains and Adamawa Highlands. They are located where people took up defensive positions on hillsides and developed very intensive systems of terrace farming. Some have since been abandoned, with the people reverting to shifting cultivation in the lowlands. Elaborate terrace farming systems are still being used and maintained at Maku, in the Awgu area of Anambra State in Nigeria. Upper slopes (A) and floodplains (B) are both used in this way.

A

(i) Farm sizes are small, simple tools used but settlement permanent.

(ii) Terraces built of stones roughly along the contours with adequate or good water management techniques.

(iii) Fertility of soil maintained with farm and household refuse and animal waste.

(iv) A range of crops grown in mixed or monoculture and rotated – very intensive system with vegetables of major importance.

(v) Very good use made of different topographic situations or soils at different elevations with tree crops on top and some in valley bottoms, annual staples on terraces in between.

(iv) Population pressure very high and migration rate also high.

(vii) Erosion hazard high on footpaths along slopes and where terrace walls break down.

B

(viii) Floodplain agriculture takes place on very rich alluvial soils and sometimes on hydromorphic soils.

(ix) Very high yields of yams, bananas and rice are produced. Often the farmer has to race with the flood and crops may be lost unless there is good water control.

(x) Fishing may be a very important occupation.

(xi) On hydromorphic soils crops and vegetables are produced in the dry season.

(xii) Erosion hazard not high on the flat lowlands, except that associated with floods, especially on slopes.

6. *Mixed farming*

(i) Mainly involves production of a range of livestock (cattle, sheep, goats, etc.) in combination with systems of cultivation of crops.

(ii) Consists mainly of two kinds: (a) traditional types found among the Serere of Senegal, where it is declining with increased interest in groundnuts, the Fulani of the Foutta Djallon area of Guinea and Shuwa Arabs of northeastern Nigeria, and (b) more modern aspects of mixed farming introduced into areas such as Kano (Nigeria) in the 1940s with livestock kept for work and manure.

(ii) Soil fertility usually maintained around homesteads and on farms with farmyard manure.

(iv) Erosion hazard very high, especially in the savannah where there is no adequate cover at the end of the dry season.

7. *Livestock ranching*

(i) Large-scale ranching projects such as the one at Obudu in southeastern Nigeria have or are currently being developed in different parts of West Africa.

(ii) Erosion hazard usually associated with poor range management, overstocking and overgrazing. Gully erosion most serious along animal trails and waterholes. With increasing experience and stable economic conditions, management should improve, and erosion hazard be reduced.

8. *Intensive livestock production*

(i) These projects involve the rearing of cattle, pigs, poultry and dairy animals in intensive systems.

(ii) Erosion hazard is absent or limited where animals are fed indoors.

(iii) Where they are grazed, trampling of vegetation and grazing may expose some areas to erosion.

9. *Large-scale plantations*

(i) Many kinds of large-scale plantations owned by private individuals, cooperatives and governments are being developed in many parts of West Africa.

(ii) Of the three listed in Table 5.7, the lowest erosion hazard is associated with tree crop plantations such as rubber and oil palms, especially where they are grown with cover crops such as *Pueraria phaseoloides*.

(iii) The highest erosion hazard is associated with large-scale mechanized food and arable crop farms involving row crops (Obeng *et al.*, 1973).

(iv) Baldwin (1957) gives a very interesting example of this in *The Niger Agricultural Project*, at Mokwa, the failure of which he regarded as 'the most disastrous consequence of lack of adequate preliminary knowledge'. Very spectacular erosion gullies 1·8 m wide, 0·9 m deep and 1·6 km long resulted after two years, from inadequate attention to the erosion hazard. The same mistakes are repeated in many of the schemes now being introduced.

10. *Specialized horticulture*

(i) Market gardens and large-scale horticultural projects are developing in different parts of West Africa, especially close to urban centres.

(ii) As an aspect of intensive production systems, mulching of beds, construction of terraces and tied beds, etc., have often been done as regular practice.

(iii) Where beds are not protected by mulching and not aligned parallel to the contour, erosion hazard may be serious.

(iv) Moreover, certain types of irrigation systems on sloping land may introduce erosion problems.

(v) Where fruit trees are grown in plantations with cover crops, erosion is very much minimized.

5.2.3. CONCLUSIONS

On the basis of the above review of the erosion hazards in different farming systems in West Africa and their associated farming practices or operations, it is concluded that:

(i) traditional systems of soil management do not involve serious erosion hazard as long as the periods of fallow are reasonably long, vegetation cover is maintained and population pressure is low;

(ii) with increasing population pressure, overgrazing or change to more intensive systems of production on light soils and slopes with methods developed for extensive agricultural systems, erosion becomes a serious problem;

(iii) mechanization of clearing and cultivations still presents problems, especially on large-scale farms for growing row crops.

(iv) changes in traditional farming systems require appropriate changes in crop and/or animal inputs based on sound principles of soil conservation; and

(v) it is not only in farming but also in various aspects of multiple land use that sound conservation practices and protection of the environment should be emphasized.

Erosion has been a world-wide problem for centuries and still remains so in West African agriculture. It can be minimized by making everyone aware of the

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problem, by the enforcement of sound soil conservation legislation where necessary and feasible, and by the development of scientific water, soil and crop management techniques for catchments or watersheds of different sizes and for various topographic situations. The lowlands and hydromorphic soils of the humid tropics of West Africa hold high potentials for increased agricultural production without soil erosion and degradation, but the development of the appropriate technology for achieving this has received too little attention.

More effort and resources should be devoted to the prevention of erosion through research aimed at the development of better land clearing, water and soil management techniques for continuous cropping systems. This can only be achieved through the cooperation of scientists in different disciplines and across international boundaries.

REFERENCES

Adler, E. D., 1951, Soil conservation in the Union of South Africa, *African Soils*, I (1), 25-35.

Ahn, P. M., 1970, *West African Soils*, West African Agriculture Vol. I, Oxford University Press, London.

Anon, 1957, Enquiry concerning the drying up of land in French West Africa, Climatological Abstracts, *African Soils*, I (1), 91-94.

Anon, 1974a, Erosion causes havoc, *Daily Times* (Lagos), January 24, 1974, p. 1.

Anon, 1974b, Problem of soil erosion, *Daily Times* (Lagos), Editorial, January 28, 1974.

Baldwin, K. D. S., 1957, *The Niger Agricultural Project* Blackwells, Oxford.

Baver, L. D., 1940, *Soil Physics*, Wiley, New York

FAO, 1960, *Soil Erosion by Wind and Measures for its Control on Cultivated Lands*, FAO Agricultural Development Paper No. 71, FAO, Rome.

FAO, 1965, *Soil Erosion by Water, Some Measures for its Control on Cultivated Lands*, FAO Agricultural Development Paper No. 81, FAO, Rome.

Floyd, B., 1969, *Eastern Nigeria*, Macmillan, London

Fournier, F., 1967, Research on soil erosion and soil conservation in Africa, *African Soils*, 22 (1), 53-96.

Gourou, P., 1956, The quality of land use of tropical cultivations, In W. L. Thomas, *Man's Role in Changing the Face of the Earth*, University of Chicago Press, Chicago, pp 336-349.

Greene, H., 1951, Soil conservation in British Colonial Africa, *African Soils*, 1, 13-19.

Greenland, D. J., 1973, Evolution and development of shifting cultivation, *Shifting Cultivation and Soil Conservation in Africa*, FAO Soils Bulletin, No 24, FAO, Rome, pp 5-13.

Grove, A. T., 1951, Land use and soil conservation in parts of Onitsha and Owerri Provinces, *Geological Bulletin of Nigeria*, No. 21, Zaria.

Grove, A. T., 1952, Land use and soil conservation in the Jos Plateau, *Geological Survey of Nigeria Bulletin*, No 22, Zaria.

Guillaume, M., 1951, Soil conservation in the inter-tropical soil of French Union, *African Soils*, I (1), 21-24.

Guilloteau, J., 1955, The improvement of agricultural economy in Senegal, summary of Professor Porteres' Mission Report, *African Soils*, 3, 11-44.

Jurion, P., 1956, Soil conservation in the Belgian Congo, *African Soils*, 4, 35-44.

Kittredge, J., 1973, *Forest Influences*, Dover, New York.

Lal, R., 1973, Soil erosion and shifting agriculture, *Shifting Cultivation and Soil Conservation in Africa*, FAO Soils Bulletin, No. 24, FAO, Rome, pp 48-71.

Langdale-Brown, I., 1968, The relationship between soils and vegetation, in R. P. Moss, *The Soil Resources of Tropical Africa*, Cambridge University Press, London.

Laut, P., 1971, *Agricultural Geography*, Vol. 1, 1st edn, Nelson, London.

Middleton, H. E., 1952, Modifying the soil physical system: modification of the physical properties of virgin soil in preparing it for cultivation, In B. T. Shaw, *Soil Physical Condition and Plant Growth*, Vol. II, Agronomy Monographs, Academic Press, New York, pp. 24-41.

Morgan, W. B., and J. C. Pugh, 1969, *West Africa*, Methuen, London.

Mouttapa, F., 1973, Soil aspects in the practice of shifting cultivation in Africa and the need for a common approach to soil and land resources evaluation, *Shifting Cultivation and Soil Conservation in Africa*, FAO Soils Bulletin No. 24, FAO, Rome, pp 37-47.

Ofomata, G. E. K., 1964, Soil erosion in the Enugu region of Nigeria, *African Soils*, 9, 321-348.

Portères, R., 1952, Linear cultural sequences in primitive systems of agriculture in Africa and their significance, *African Soils*, 2, 15-28

Portères, R., 1955, Agricultural crisis in Senegal, *African Soils*, 3, 41-52

Ramsey, D. M., 1968, Land use in Nigeria, *Samaru Agricultural Newsletter*, 10 (4), 73-81.

Russel, E. W., 1968, Some agricultural problems of semi-arid areas, In R. P. Moss, *The Soil Resources of Tropical Africa*, Cambridge University Press, London

Shaw, B. T., 1952, (ed.), *Soil Physical Condition and Plant Growth*, Academic Press, New York.

Strahler, A. N., 1956, The nature of induced erosion and aggradation, in W. L. Thomas, *Man's Role in Changing the Face of the Earth*, University of Chicago Press, Chicago.

Udo, R. K., 1970, *Geographical Regions of Nigeria*, Heinemann, London

Vine, H., 1968, Developments in the study of soils and shifting agriculture in tropical Africa, In R. P. Moss, *The Soil Resources of Tropical Africa*, Cambridge University Press, London, pp. 89-119.

Webster, C. C., and P. N. Wilson, 1966, *Agriculture in the Tropics*, Longmans, Green, London.

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RE-EVALUATION OF INDIGENOUS METHODS

Okigbo, B.N. and D.J. Greenland. 1976. From Multiple cropping, R.I. Papendick, et al., eds. American Society of Agriculture, Special Publication no. 27. Madison, WI: ASA.

Intercropping Systems in Tropical Africa

B. N. Okigbo and D. J. Greenland[1]

Tropical Africa lies south of the Sahara Desert bounded by imaginary lines both north and south of the equator. The northern line runs from Cape Blanc on the Atlantic coast of Mauritania due east to the northern tip of Ethiopia on the Red Sea coast. The southern line traverses east from Mocamedes on the Atlantic coast of Angola to the southernmost tip of Mozambique on the east coast of Africa. It is a land 5,150 km long and 7,400 km wide with an area of about 22×10^6 km^2 (Kimble, 1962). The area extends over the entire equatorial belt of Africa and latitudinally to about 20°N and 26°S. This land mass which is about twice the area of the U. S. exhibits great diversity in relief, climate, vegetation, and crops grown (Fig. 1, 2, 3, 4).

Tropical Africa has a population of over 290 million people of many racial backgrounds and according to Grove (1970) up to 800 linguistic groups. There are 40 countries represented with widely different cultural, economic, colonial, and political backgrounds and experience. These factors in addition to the level of technological development and resource availability (Norman, 1974) constitute the basis of diversity in the number of crops grown and variations in cropping and farming systems. In this paper, characteristics of cropping systems in traditional farming practices are considered as a basis for a survey of multiple cropping systems in tropical Africa and a review of related research in relevant countries.

FARMING SYSTEMS AND ASSOCIATED CROPPING PATTERNS

Of the 13 major agricultural regions in Whittlesey's (1962) classification, only nomadic herding, shifting cultivation, rudimentary sedentary cultivation and nonrice based intensive agriculture, special horticulture, and plantation

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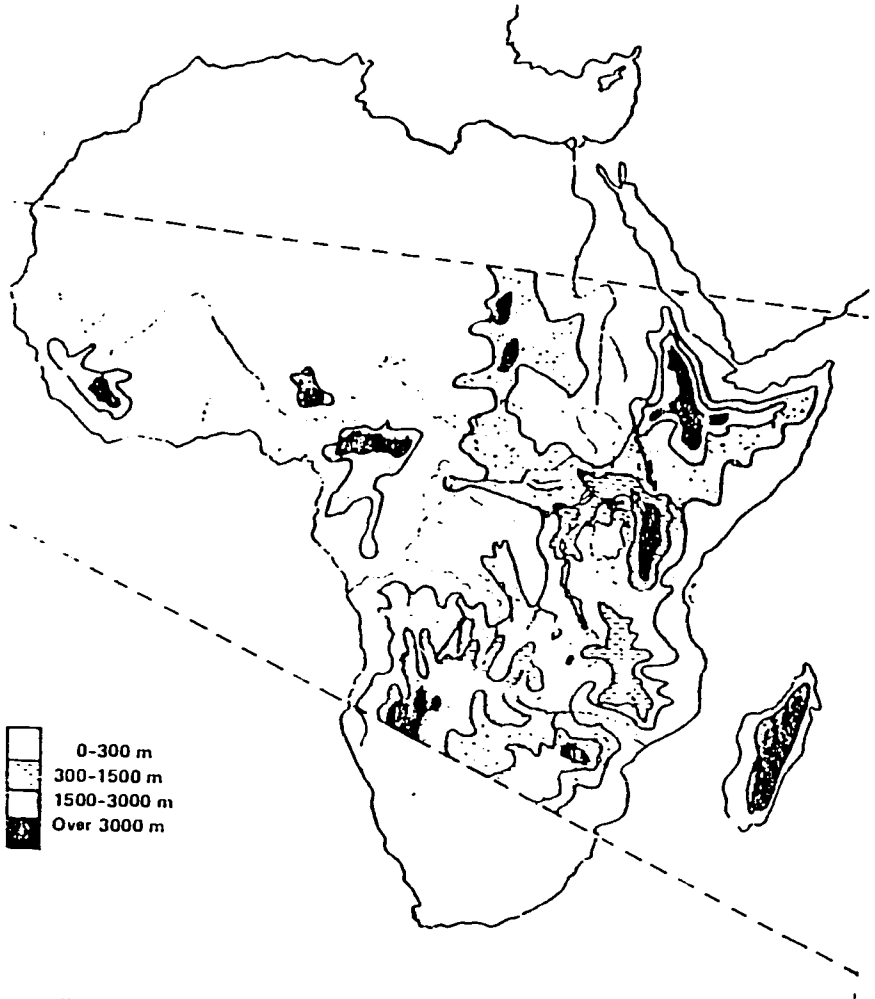

Figure 1. Major physical area of tropical Africa (Kimble & Steel, 1966).

agriculture are found in tropical Africa. Since then, attempts have been made to develop more functional and acceptable classifications of the farming systems of the world (Dumont, 1970; Duckham & Masefield, 1971; Laut, 1971; Evenson et al., 1973; Grigg, 1974). Classifications of farming systems with emphasis on the agriculture of the tropics include those of Allan (1965), Miracle (1967), Morgan and Pugh (1969), Morgan (1959a, 1969), Floyd (1969), Boserup (1970), Ruthenberg (1971, 1974), Bennch (1972) and Greenland (1974). With the exception of Ruthenberg's classification which takes into account vegetation, migration, rotation, clearance, cropping, and tool systems, most methods of classifying farming systems of the tropics are based on differences in intensity of cropping and variations in the duration of the fallow period for the restoration of soil fertility.

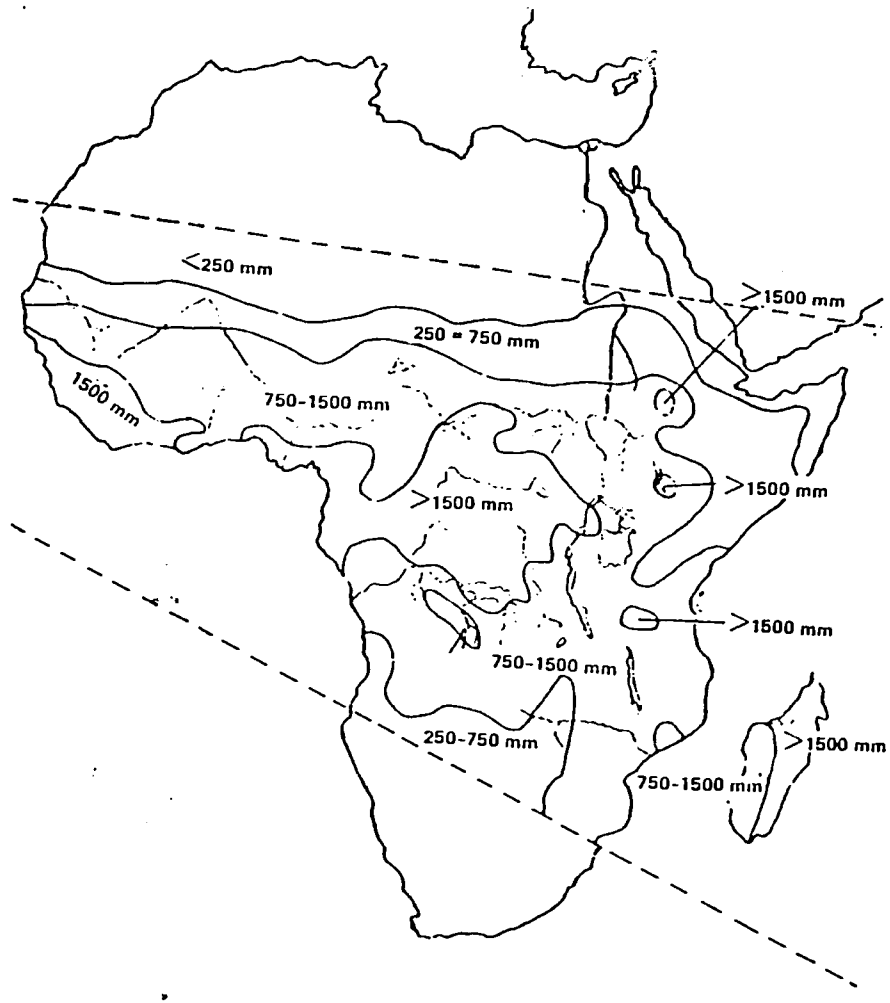

Figure 2. Tropical Africa, mean annual rainfall (Kimble & Steel, 1966).

With the exception of some parts of Africa where farming methods are patterned after the modern systems of Europe and plantation agriculture, multiple cropping constitutes a major component of the existing farming systems. However, these systems are transitory stages in the evolution of either potentially permanent systems under proper management of resources and adjustment to change or degenerating systems that are subject to final collapse under poor management of resources and failure to adjust to change brought about by population pressure and other processes. Consequently, they are not necessarily in equilibrium with the biological and cultural environments of the farmer as might have existed centuries ago under low population pressure when adjustments to conditions came about naturally by providence or after long periods of gradual evolution.

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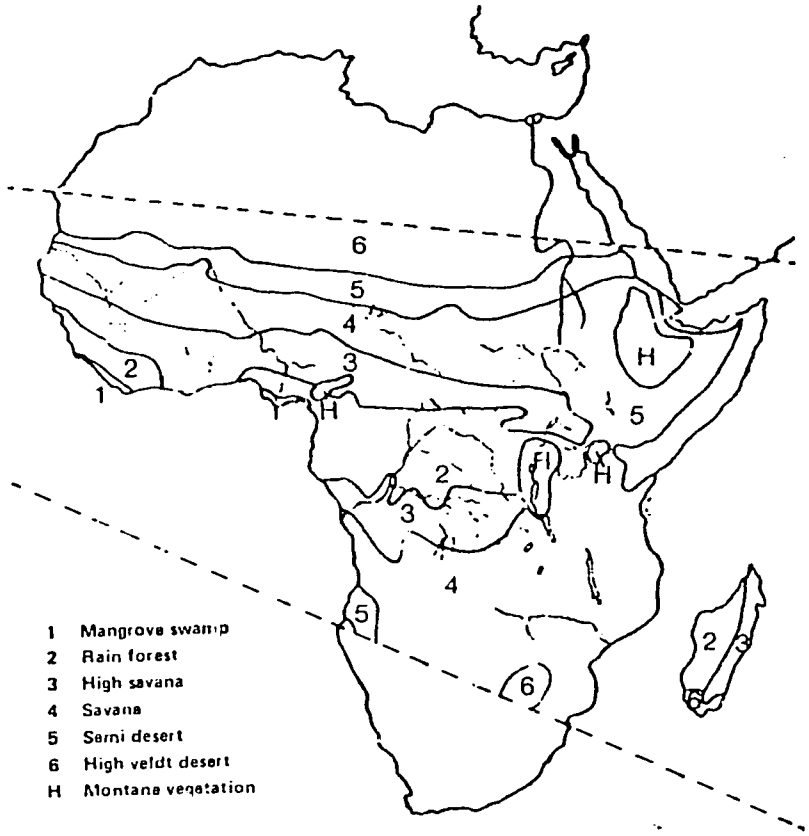


Figure 3. Africa, natural vegetation zones (Jarrett, 1966).

Classifications which provide a suitable background for the understanding of the developments that led to the existing cropping systems, their complexities, similarities, and contrasts are those of Porteres (1962) and Benneh (1972). Porteres, on the basis of his studies of origin of cultivated plants and agriculture in Africa, arrived at two main conclusions. First, Africa evolved two agricultural complexes—a *seed agricultural complex* characteristic of open unforested regions analagous to our savannas of today and a *vegecultural complex* peculiar to forested regions and involving cultivation of roots, tubers, and cuttings in gardens rather than fields. Second, differences between these two complexes have gradually disappeared as crops and techniques developed elsewhere were adopted within the traditional systems. Benneh's (1972) classification which covers the types of existing farming systems in West Africa is based on methods of soil fertility maintenance in fallow and permanent systems prevalent on farms of different sizes consisting of the following categories:

A. Traditional and transitional systems

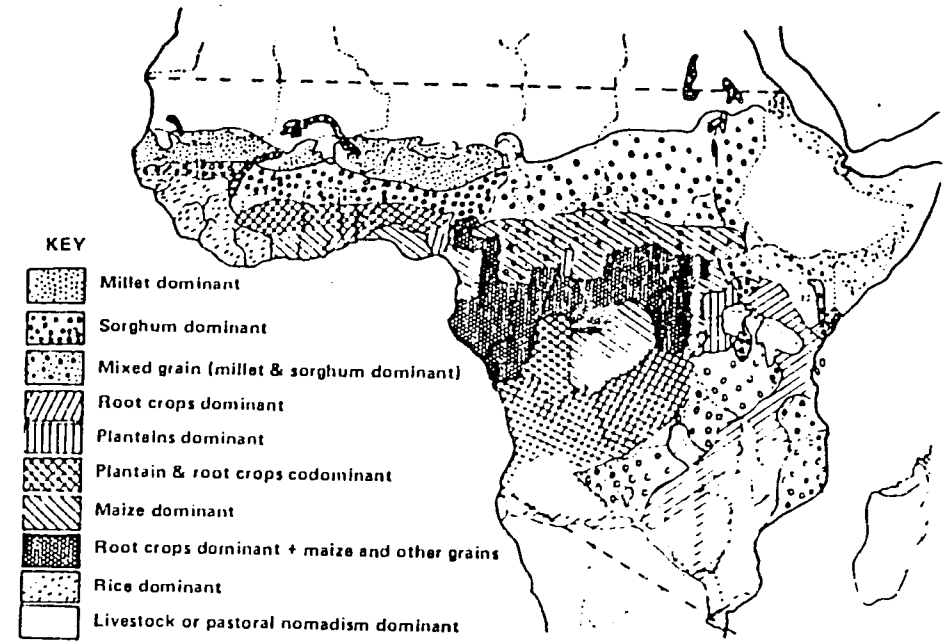


Figure 4. Crop dominant regions (Johnston, 1958; Miracle, 1966; Morgan & Pugh, 1969; Morgan, 1969; Matheson & Bovril, 1950).

1. Nomadic herding:
   shifting cultivation (Phase I), $L > 10$[2]
2. Bush fallowing or land rotation:
   shifting cultivation (Phase II), $L = 5 - 10$
3. Rudimentary sedentary agriculture:
   shifting cultivation (Phase III), $L = 2 - 4$
4. Compound farming and extensive subsistence agriculture:
   shifting cultivation (Phase IV), $L < 2$
5. Terrace farming and floodland agriculture
6. Mediterranean agriculture (traditional)

B. Modern farming systems and their local adaptations
1. Mixed farming
2. Livestock ranching
3. Intensive livestock production (poultry, pigs, dairying)
4. Large scale farms and plantations
   a. Large scale food and arable crop farms based on natural rainfall
   b. Irrigation projects involving crop production
   c. Large scale tree crop plantations
5. Specialized horticulture
   a. Market gardening
   b. Truck gardening and fruit plantations
   c. Commercial fruit and vegetable production for processing.
6. Mediterranean agriculture (modern)

[2] $L = C + F/C$ where C = Cropping Period, F = Fallow Period, L = Land Use Factor.

The groups of farming systems under A (1b-6) and B (1, 4, 5, and 6) are those under which multiple cropping is found in tropical Africa. The complexity of these systems may be illustrated by the fact that a farmer usually operates a much diversified agricultural enterprise, often including a combination of different systems listed by Benneh (1972). For example, a farmer on an upland well-drained soil may operate a compound farm close to this homestead while at the same time maintain two or more plots under cropping systems of different periods of forest, bush, or planted fallows at varying distances from his home. In addition to this, he may practice floodland cultivation in the flood plain of a nearby river or stream. He may also raise goats, sheep and/or poultry for manure and other purposes. The cropping on the compound farm often involves major staples, vegetables and condiment plants grown in double, relay, and mixed intercropping patterns under the canopy of tree crops such as oilpalms (*Elaeis guineensis*), mangoes (*Mangifera* sp.), and oranges (*Citrus* sp.). The compound farm or homestead garden thus carries more species of cultivated plants than bush fallow farms since on the latter only major staples and a few protected trees may be grown.

SOME CHARACTERISTICS OF TRADITIONAL FARMING AND ASSOCIATED CROPPING SYSTEMS

A simplistic model of traditional farming would consist of a concentric pattern of fields on which are practiced various methods of fertility maintenance or fallowing, clearance systems, production of different numbers of species and varieties of crops and cropping patterns and sequences according to the prevailing customs and the needs of the farmer. Based on this concept, the following generalizations can be made of these systems:

1. There is a diversity of farming systems ranging from "true" shifting cultivation where the settlement is moved to permanent cultivation.
2. "True" shifting cultivation is rare and restricted to parts of Rhodesia (Allan, 1965), the Ivory Coast and the Cameroun Republic (Morgan, 1969; Grigg, 1974).
3. Permanent cultivation occurs in (i) compound farms, kitchen or homestead gardens, (ii) some soils of high fertility, (iii) confined sites (such as steep slopes of Maku in the East Central State of Nigeria where terrace farming is practiced and on islands such as the Ukara Island in Lake Victoria, and (iv) overcrowded areas of high population densities such as in the Ibo and Ibibio areas of the east central State of Nigeria, the eastern rice-growing slopes of the Malagasy Republic and Kano close-settled zone of the north central State of Nigeria (Morgan, 1969).
4. The compound farm system is the most widespread permanent cropping or farming system and often forms the center from which paths lead to other field systems. The largest number of crop species in mixtures are found in compound farms since the crops there are not only grown for food but also for oils and fats, condiments and spices, masticants and stimulants, drugs, fiber, structural materials, animal feed, demarcation of boundaries, firewood, ornamentals, shade, protection and privacy of the homestead, religious and social functions, and various other uses. Its development as a regular feature in the traditional farming systems is related to two phenomena: i) The division of labor between the sexes in which the women are responsible for cooking and the provision of soups and sauces. The main starchy staples are primarily produced by men. They are eaten with fresh condiment plants, spices, and vegetables at available close range through the year and ii) The fact that with frequent clearing of forests and bushes, useful trees harvested from the wild or protected in fallows are gradually disappearing and their cultivation in compound farms ensures that their products are readily available and that they do not become scarce or extinct.
5. Semipermanent long and short bush or planted fallow systems vary in cultivation period relative to length of fallow. Factors are the natural fertility of the land, distances from the homestead, methods of fertility maintenance, and population pressure. In semipermanent fields, major staples are predominant with a few subsidiary crops, all much less in number than in compound farms.
6. The most important staples and cash crops are usually grown the first year following clearance of forest, natural bush, planted fallow or grassland. The number of crop species decreases as the number of years of continuous cropping increases.
7. Intercropping is widespread with the highest complexity in the compound gardens, especially in the rainforest where annual staples, vegetables, and perennial fruit trees are intercropped. Tables 1, 2, and 3 show the extent to which intercropping is practiced in different ecological zones in Nigeria and Uganda. In farms or fields located at varying distances from the homestead, semi-wild protected and selected wild tree crops, but rarely cultivated species, are found.
8. The growing of more than one crop on the same land in 1 year in traditional farming systems takes the form of mixed intercropping and relay intercropping more so than sequential cropping involv-

Table 1. Areas in important crops in Nigeria in relation to the system of production in 1970-1971

Crops	Hectarage sole	Hectarage mixed	Percentage mixed
	ha X 10^{-3}		%
Yams	503.7	733.2	59.2
Cassava	307.2	112.6	26.8
Cocoyam	27.4	173.9	86.4
Rice	103.9	143.3	58.0
Maize	355.2	1092.8	75.5
Melon	25.9	334.3	92.8
Cowpeas	39.0	3777.1	99.0
Groundnut	19.8	419.7	95.5
Cotton	130.2	524.5	80.1
Guinea corn	1152.0	4557.0	79.8
Soya-bean	48.2	51.8	100.0
Benniseed	36.8	41.3	52.9
Millet	510.9	4411.1	89.6

Table 2. Area of crops grown in most of Uganda according to area and percentage of system of cropping in 1963–1964 (Jameson, 1970)

Crop	Area in hectare		Percentage of crop grown in			Overall mixed cropping
	Pure	Mixed	Pure	Mixed predominant	Mixed not predominant	
	ha (000)		%			
1. Beans	57.9	250.6	18.7	10.3	71.0	81.3
2. Cowpeas	29.6	47.8	38.2	6.3	55.5	61.8
3. Cassava	85.0	84.6	50.1	10.3	39.6	49.9
4. Robusta coffee	114.6	174.9	39.6	33.0	27.4	60.4
5. Arabica coffee	6.1	10.5	36.6	--	--	63.4
6. Cotton	367.6	130.4	73.8	21.2	5.0	26.2
7. Groundnuts	67.2	86.6	43.7	33.8	22.5	56.3
8. Maize	44.9	232.0	16.3	14.6	69.1	83.7
9. Sorghum	135.6	115.8	54.0	7.1	38.6	46.0
10. Finger millet	226.7	206.1	52.4	41.3	6.3	47.6
11. Peas	17.4	4.0	81.1	--	--	18.9
12. Pigeon peas	12.6	39.7	24.0	7.0	69.0	76.0
13. Bananas	268.8	195.5	57.9	20.9	21.2	42.1
14. Sesame	51.0	53.0	49.0	19.1	31.9	51.0
15. Sweet potatoes	73.7	11.7	86.3	4.7	9.0	13.7

ing monocultures. Row intercropping and alternate strip intercropping are not common except where animals or tractors are used in cultivation.

9. Classical crop rotations involving sequences of crops grown in monoculture are rare in traditional farming systems. More common are the "pseudo-rotations" in which mixed intercropping with different species are followed by different sets of dominant and subsidiary crops also in mixed intercropping (Allan, 1965). Some crops are relay intercropped with the preceding ones.
10. Farm sizes are usually small ranging from less than 1 ha up to 5 ha. Farm sizes tend to be greater but number of crops in mixtures lower in moving from the rainforest to savanna or drier areas.
11. Cash or export crops are more likely to be grown as sole crops or in association with fewer crops than noncash staples.
12. Farming involves simple tools and much human labor.
13. The most widespread land clearing systems involve the use of fire.
14. With the exception of irrigation, some locations in semiarid and arid areas, most cropping systems rely on rainfall. The cropping patterns and mixtures are related to the uncertainities in rainfall distribution and intensity.

FACTORS CONTRIBUTING TO CHANGES IN CROPPING SYSTEMS AND ADAPTATIONS TO PREVAILING CONDITIONS

Variations and changes in cropping systems have arisen from:

1. The introduction of Asian crops [taro (*Colocasia antiquorum* sp.), water yam (*Dioscorea alata*), bananas (*Musa* sp.), rice (*Oryza sativa*

Table 3. Food crops and other useful plants found in crop mixtures in compound and outlying farms in parts of southeastern Nigeria

Crop plant group	Area of sample									
	A* 0.003–0.45 Ha		B* 0.04 Ha		C* 0.04–0.4 Ha		D* 0.04–0.5 Ha		E* 0.04–0.5 Ha		Mean percentage frequency
	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	
1. Roots & tubers	1–12	5	4–6	5	5–8	7	1–8	4	7–9	8	47
2. Cereals & other starchy staples	0–3	1	1–2	1	2–3	2	0–4	2	2–3	2	38
3. Leaf vegetables	3–7	4	0–4	2	4–8	6	10–11	6	2–8	5	27
4. Fruit vegetables	4–5	4	1–3	2	5–6	5	0–6	2	3	3	44
5. Legumes	1–5	3	0–4	2	2–4	2	0–3	1	0–3	2	33
6. Fruits, nuts & oil plants	1–14	5	0–1	1	10–11	10	2–15	7	5–12	9	20
7. Spices & beverages	0–3	1	0–1	1	2–6	4	0–9	4	1–7	4	18
8. Miscellaneous useful plants	0–7	2	0–1	0	10–14	13	1–29	11	4–18	12	11
Range in total number of species or cultivars	6–52		4–19		40–48		6–62		25–42		

* A = Derived Savanna; B = Transition Zone—Derived Savanna-Oil Palm Bush; C = Oil Palm Bush—High Population Density; D = Oil Palm Bush—Medium-High Population Density; E = Oil Palm Bush—High Population Density.

L.)] starting from the first three centuries A.D. and American crops [maize (*Zea mays* L.), cassava (*Manihot esculenta*), sweet potatoes (*Ipomoea batatas*)] in the 16th century A.D. and later (Shaw, 1972).
2. Population growth following the introduction of Asian and American crops and modern advances in medicine, sanitation and public health which have resulted in increasing pressure on the land.
3. The development of markets for perennial crops (Morgan, 1959a).
4. Expansion of cassava production due to its adaptation to shorter periods of fallow resulting in lower soil fertility and demands for cheaper staple foods in urban centers (Morgan, 1959b). Moreover, in areas where the dry season ranges from 1 to 5 months, cassava is the only crop that can thrive without irrigation.
5. Development of commercial production of food crops and market gardening especially close to urban centers.
6. Development of railways, road systems, and markets and the growth of settlements and farms along roads and railways and close to markets (Morgan, 1959b).
7. Increased fruit and vegetable production for sale and in support of local canning industries.

Crop Diversity and Spatial Arrangement

A common feature of traditional farming systems is production of several species of crop plants and numerous varieties of each species by each farmer. In Zaire, the Medje grew as many as 80 varieties of the 30 species of food crops they cultivated in 1911 (Miracle, 1967). Of these, there were 27 varieties of bananas and plantains (*Musa* sp.) and 22 varieties of yams and related crops. The various varieties of each crop exhibit different characteristics, mature at different times, and may be adapted to different ecological situations and cultural practices. While crops are apparently established haphazardly in mixed culture, close study of planting patterns indicates that both on the macro and micro level of a given landscape, the pattern of land use or planting used in traditional cropping systems usually involves location and spacing of plants in such a way as to:

1. take advantage of local topographic features, toposequences, microrelief and other related peculiarities,
2. disperse individual plant species at such wide spacing as to allow other crops to be grown in between without unnecessary overlapping of their canopies,
3. ensure that crop cover is adequate to effectively control soil erosion and weeds, and
4. ensure that heliophytes are grown more in open spaces while shade tolerant species such as cocoyams (*Colocasia esculenta* and *Xanthosoma sagittifolium*) are located under trees and along hedge rows.

Where annual staples are uniformly planted among tree crops in compound farms, heavy pruning of the tree crops is usually carried out to ensure that light reaches the ground level. Whether crops are grown on mounds, beds, ridges, or on the flat, their spatial arrangements and frequencies in mixtures are usually related to their importance in the diet and sometimes to

their uses. Vegetable crops such as cucurbits (*Cucurbita* spp.), cowpeas (*Vigna* sp.), bitter leaf (*Vernonia amygdalina*), and peppers (*Capsicum* sp.) which are harvested for household use are usually planted along the edges of the garden or along fences surrounding gardens close to the homestead. The ingenuity involved in the utilization of various parts of the large mounds on which different crops are grown in a hydromorphic soil of the Abakaliki area of the east central State of Nigeria is illustrated in Figure 5. The crops are located on the mounds according to their root systems and in relation to their tolerance to high water tables.

Various methods of utilizing special topographic and other features include: the concentration of sugarcane (*Saccharum officinarum* L.), rice and off-season vegetable crops in depressions and valley bottoms, the location of pineapples (*Ananas comosus*) and fruit trees along pathways in compound gardens, the growing of climbing crop plants such as lima beans (*Phaseolus lunatus*), climbing cowpeas and yams close to trees, shrubs, fences, hedges, and other structures which act as supports or stakes. Related to this is the location of condiment plants, fruit trees, and vegetables where they can be protected, watered, and harvested with ease. Various compound farm land use and cropping arrangements in parts of tropical Africa have been reported by Allan (1965), de Schlippe (1956), and Miracle (1967).

In addition to these intercropping patterns, small patches of pure stands of certain crops in adjacent plots are prevalent in many areas. Similarly, in smallholder market gardens close to urban centers, vegetables are grown either in pure stands or in mixtures on small adjacent beds.

REGIONAL AND COUNTRY SURVEY OF MULTIPLE CROPPING SYSTEMS

Nigeria

Nigeria stretches from 5°N to 15°N latitude and 2.5°E to almost 15°E longitudes. It has physical and climatic features which have resulted in parallel vegetation and ecological zones. These range from mangrove swamps of coastal areas, with almost no dry season in the extreme south, to the Sahel savanna zone in the extreme north with over 5 dry months. The elevation varies from sea level to over 1,000 m. A diversity of crops can be grown including roots and tubers of the tropical rainforest, crops of semiarid areas such as sorghum (*Sorghum bicolor*) and millet (*Pennisetum typhoides*) and subtropical crops such as potatoes (*Solanum tuberosum* L.) and vegetables. Unlike the countries of east, central, and south Africa, there has been no European settlement. Consequently, with the exception of a few tree crop plantations and some large-scale irrigation projects under development, the agricultural and cropping systems have been restricted to traditional smallholdings. About 55% of the farms in Nigeria are less than 1 ha and above 90% are less than 4 ha (FOS, 1972). Farm sizes are smallest in the southern states where over 86% are below 1 ha.

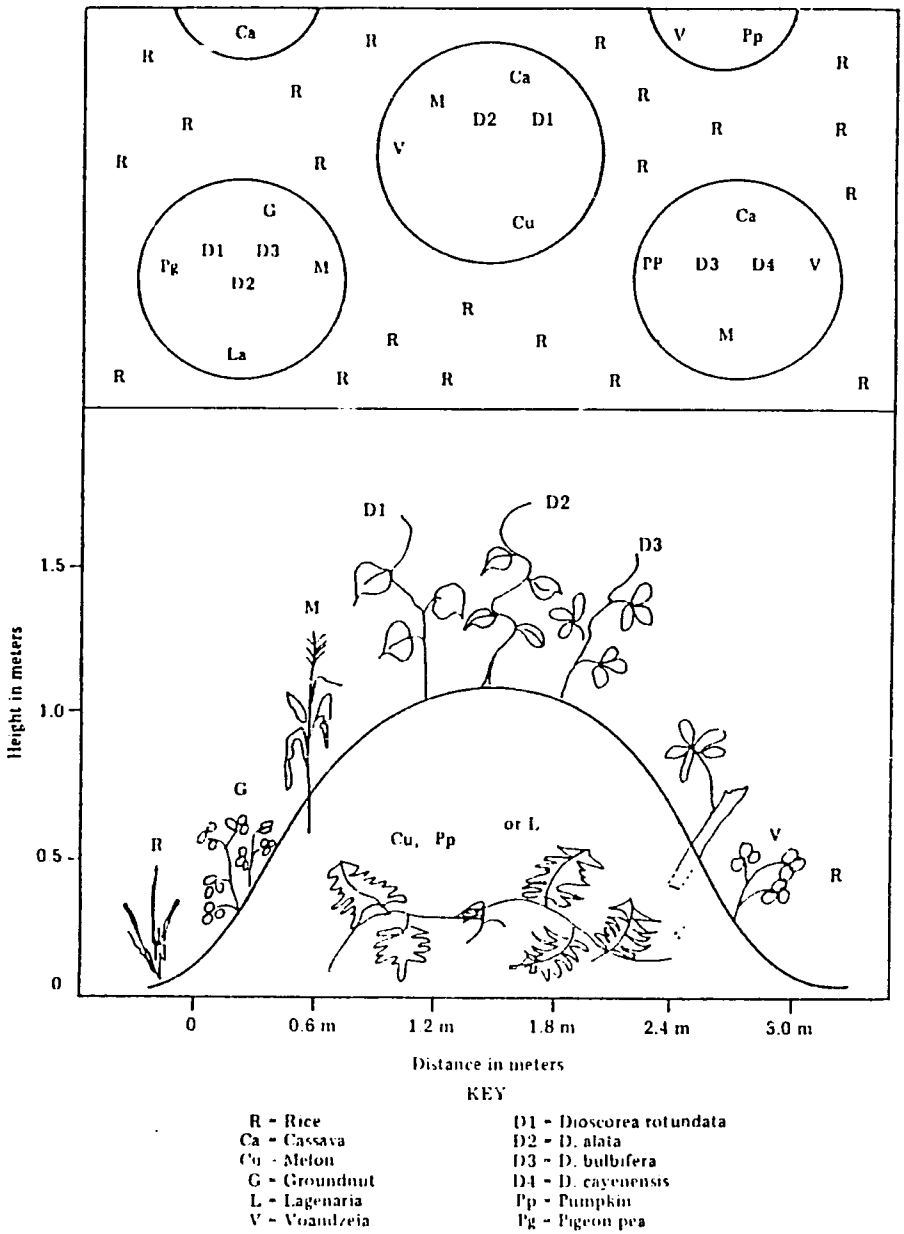


Figure 5. Spatial distribution of crops on mounds in Abakaliki, East Central State, Nigeria.

Mixed intercropping is the predominant practice for both major staples and cash crops. The number of crops involved in the mixtures may exceed 50 species and consequently many more varieties since several strains of a single crop may be grown in a field. The practice of mixed intercropping is a

long standing tradition to the extent that it sometimes militates against adoption of new varieties (Faulkner & Mackie, 1933). For example, farmers in certain parts of Nigeria could not be persuaded to grow an improved introduced and superior American cotton (*Gossypium hirsutum* L.) variety because it did not perform as well when intercropped as did the local variety.

The predominant practice of maintaining soil fertility is bush fallowing involving consecutive cropping periods of 1 to 5 years alternating with fallow periods of 2 to over 15 years, depending on the population pressure. In the densely populated areas of the East Central and Southeastern States, planted fallows of *Acioa barteri* and *Anthonotha macrophylla*, respectively, are used. Similarly, *Gliricidia sepium* is grown for the same purpose in the western State of Nigeria. Permanent cultivation with no fallow or short fallow periods is practiced in the compound farms on floodland terraces of southeastern Nigeria and the Kano close-settled areas (Morgan, 1969) Shifting cultivation proper (Phase I shifting cultivation, Greenland, 1974) is restricted to some parts of Ogoja province adjacent to the Cameroun Republic.

The most widespread multiple cropping systems consist of mixed intercropping and relay intercropping. Double cropping is limited to the growing of two crops of maize. Sometimes a double cropping, triple cropping, and alternate strip cropping systems are practiced in market gardens and with certain vegetable crops. In the southeastern states of Nigeria the dominant staples are yams, cassava, cocoyams, bananas, plantains and some maize. These crops are usually grown with subsidiary crops such as groundnuts (*Arachis hypogaea*), okra (*Hibiscus esculantus*), pumpkins (*Cucubita pepo*), melons (*Colocynthis vulgaris* and *Cucumeropsis* spp.), and leaf vegetables (*Amaranthus hybridus, Celosia argentia, Corchorus olitorus, Telfairia occidentalis*). Yams, cassava, cocoyams, bananas and plantains are also grown in western Nigeria but the bananas, plantains and cocoyams are not important in the eastern parts of the country. Tree crops grow in association with the annual and biannual staples. For example in much of southeastern and midwestern Nigeria, oilpalm constitutes part of the climax vegetation and is an important cash crop. Semiwild groves and plantations of oilpalms exist in monoculture but many palms are found in compound farms or scattered in outlying fields where they are protected. Similarly, rubber (*Hevea brasiliensis*) in the Midwest State and cocoa (*Theobroma cacao*) and kola (*Cola nitida*) in the Western State are also found in association with annual staples. The "Middle Belt" of Nigeria which consists of much of the Benue Plateau, Kwara, and northwest states grows some of the important crops of the tropical rainforest such as yams in the southern half of the area and sorghum and millet in the northern half.

Clearance systems involve slash and burn techniques. Planting on mounds or heaps and sometimes ridges is a general practice except in areas with deep alluvial or sandy soils where planting on the flat is common. The mounds attain their most impressive development in the hydromorphic soils of Abakaliki Division of the East Central State of Nigeria. Here, mounds up to 2.5 m in height and over 3 m in basal diameter are found.

Traditional cropping systems range from shifting cultivation in isolated areas near the Cameroun border to intensive sedentary cultivation (Floyd, 1969; Uzozie, 1971). Figure 6 shows the key to cropping schedules and combinations followed in this discussion.

No systematized rotations are in regular use. Crops are grown in sequence according to the number of compatible species in the mixture that can produce reasonable yields at the existing soil fertility level. Examples of crop rotations used in bush fallow and rudimentary sedentary cultivation fields at Nnewi in Onitsha Province reported by Floyd (1969) are shown in Figure 7.

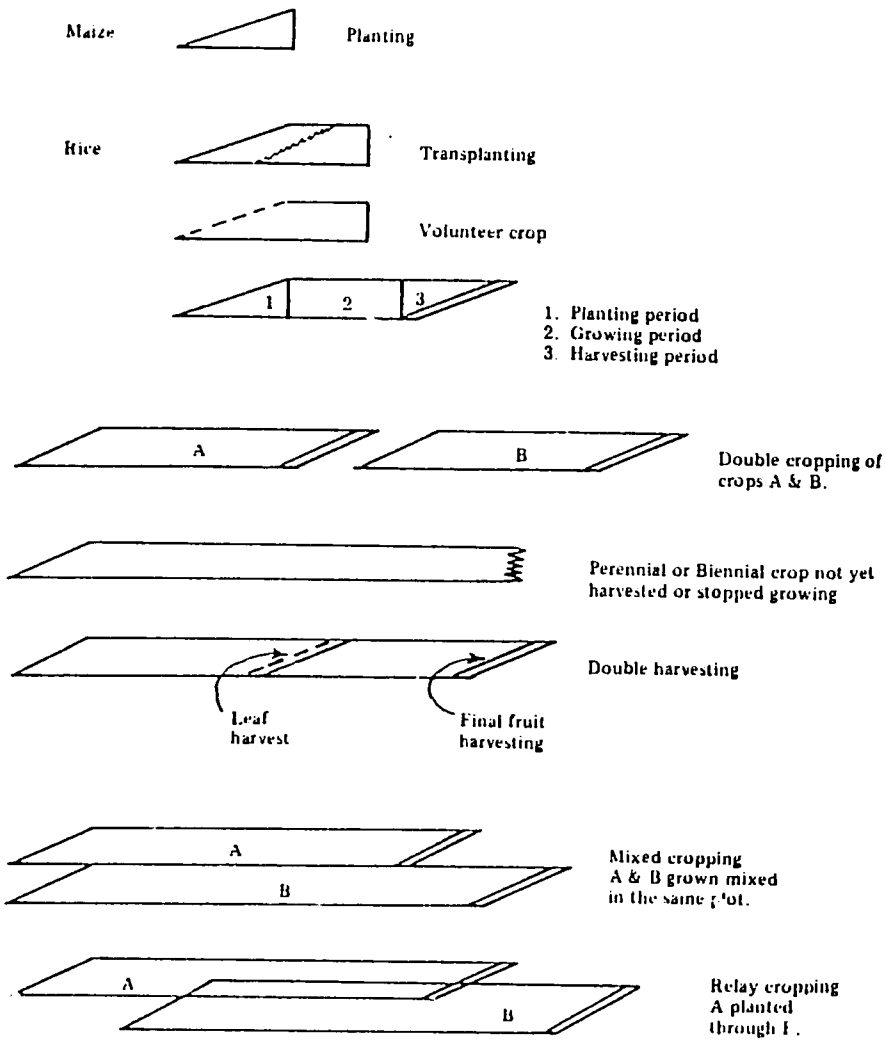


Figure 6. Key to cropping schedules and combinations.

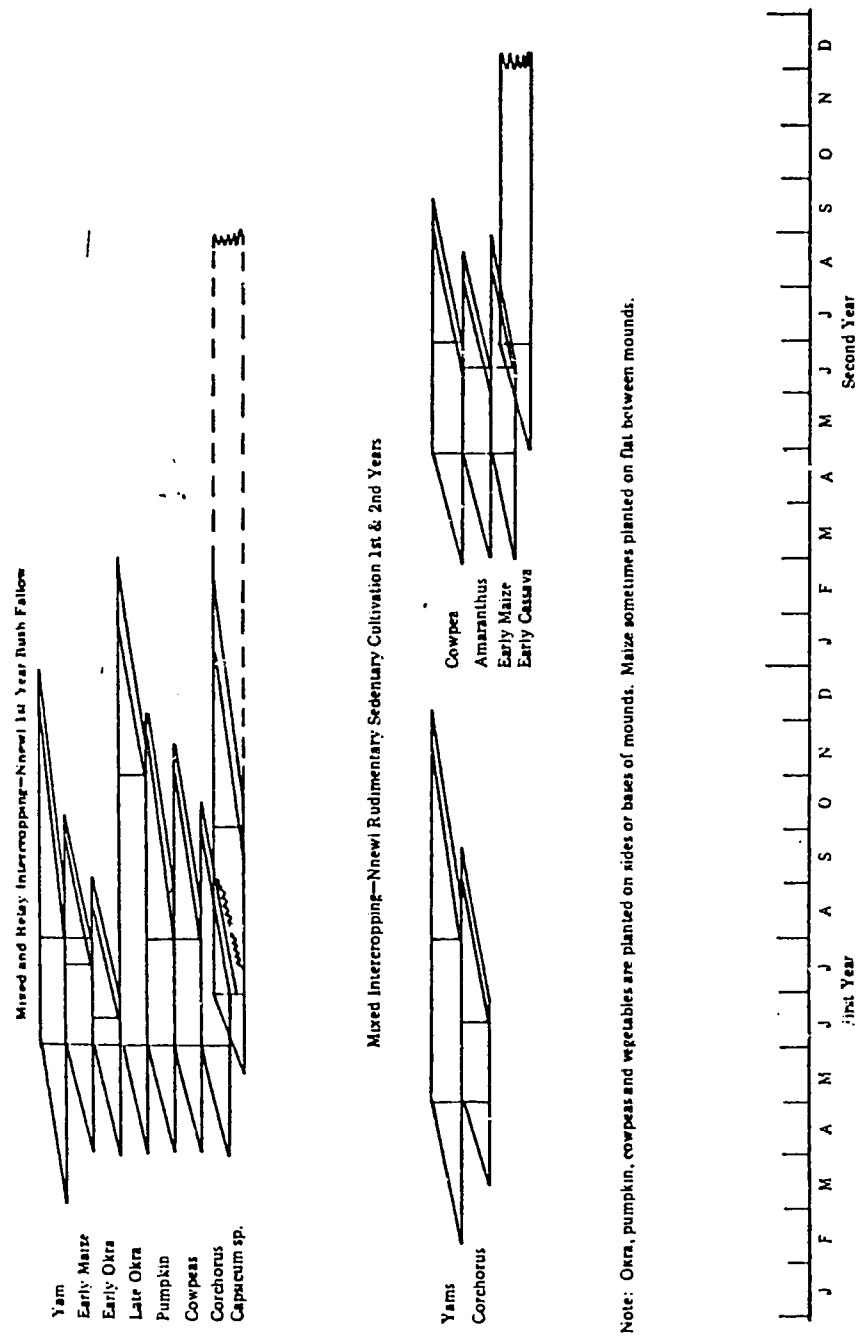


Figure 7. Schedule of planting, combinations and harvesting at Nwewi, Onitsha Province, southwest Nigeria.

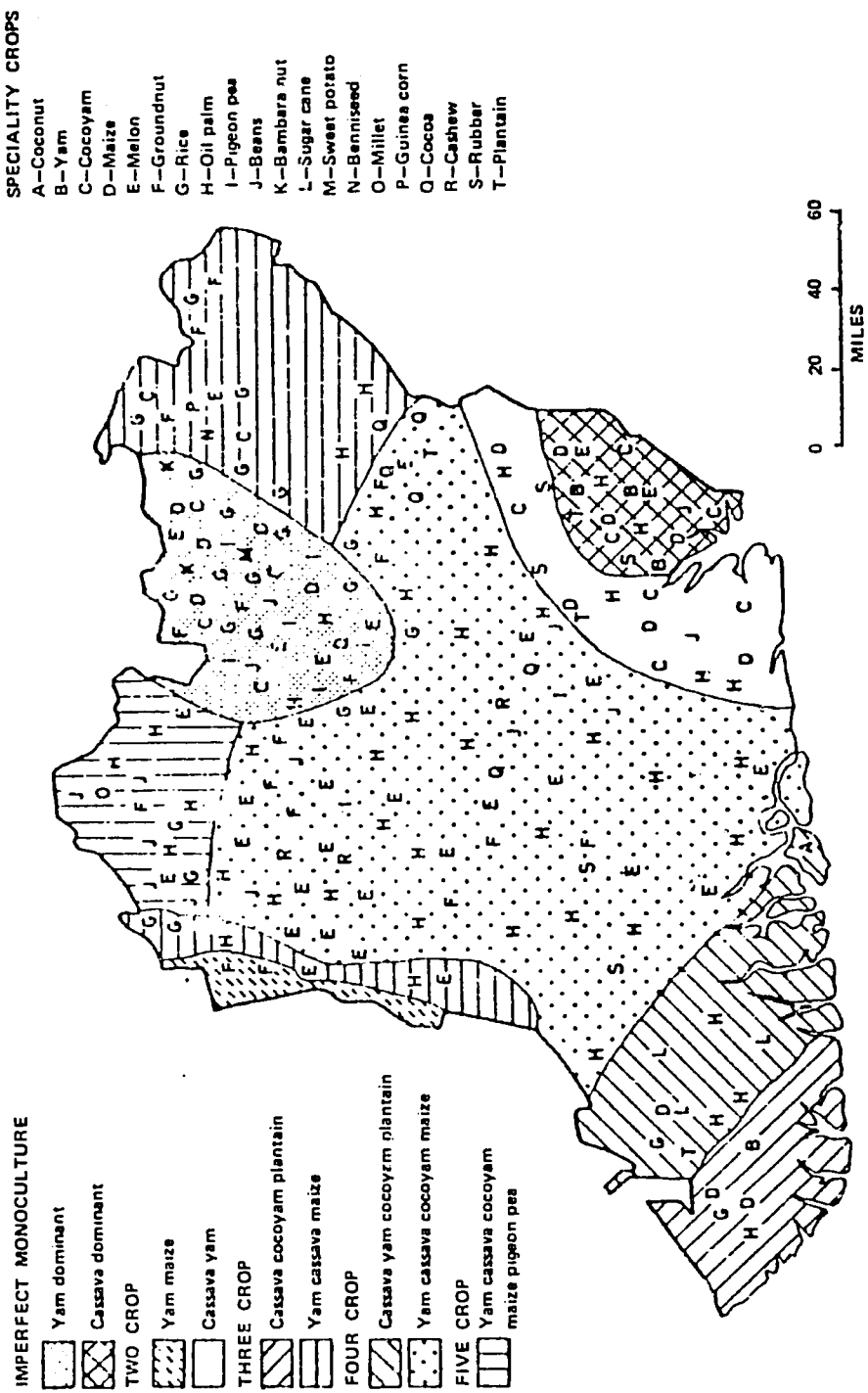


Figure 8. Crop combination areas in southeastern Nigeria (Uzozie, 1971).

Uzozie (1971) identified the following crop combination regions which are illustrated in Figure 8:

a) imperfectly developed monoculture based on yams
b) imperfectly developed monoculture based on cassava
c) yam-maize
d) cassava-yam
e) yam-cassava-maize
f) plantain-cocoyam-cassava
g) cocoyam-plantain-cassava-ya
h) cassava-yam-cocoyam-maize
i) yam-cassava-cocoyam-maize-pigeon peas (*Cajanus cajan*)

WESTERN AND MIDWESTERN NIGERIA

The dominant food crops in the Midwest and Western States are yams, cassava, maize, cocoyams, plantains and bananas, and subsidiary vegetable and other minor crops. The most important cash crops in the Midwest State are rubber and oilpalm while in the Western State cocoa and kola are the important tree crops. There are subsidiary fruit trees and perennials, nuts and oil plants which include the African pear (*Dacryodes edulis*) in the Midwest State and conophor (*Tetriacarpedium concophorum*), coconuts (*Cocos nucifera*), avocado pears (*Persea americana*), citrus fruits, pineapple, castor beans (*Ricinus communis* sp.), guava (*Psidium* sp.), etc. in both states.

Cropping sequences observed in the vicinity of Ibadan are shown in Figure 9 (Faulkner & Mackie, 1933).

In both midwestern and western Nigeria small plots of tree crops such as cocoa and rubber may be grown in semiwild groves or carefully established plantations. Otherwise, most tree crops are scattered about the farms at different spacings from each other. More of the perennial fruit trees are located nearer the homestead than nonfruit trees such as rubber. In his studies of some villages in midwestern and western Nigeria, Upton (1967) observed the following numbers of trees owned per farm family: oilpalms, 39–106; plantains and bananas, 0–83; kola trees, 0–64; and citrus trees, 0–38.

In southern Nigeria, the number of species and individual tree crops per unit area decreases with increasing distance inland until in the derived savanna belt in the northernmost parts of the rainforest zone there are intrusions of savanna cereals and other crops that thrive best in moderate to low rainfall areas. These crops include sorghum, millet, cotton, and various grain legumes. In Oyo, north of Ibadan, sorghum usually precedes yams, and the broken culms of the sorghum are used as stakes or trellises for yams.

MIDDLE BELT OF NIGERIA

The Middle Belt of Nigeria is a transition zone between the root crops-oilpalm-cocoa belt of the south and the sorghum-millet-cotton-groundnut belt of the northern states. This area is the mixed grain and root crops belt sometimes designated as the benniseed (*Sesamum indicum*) belt. This belt

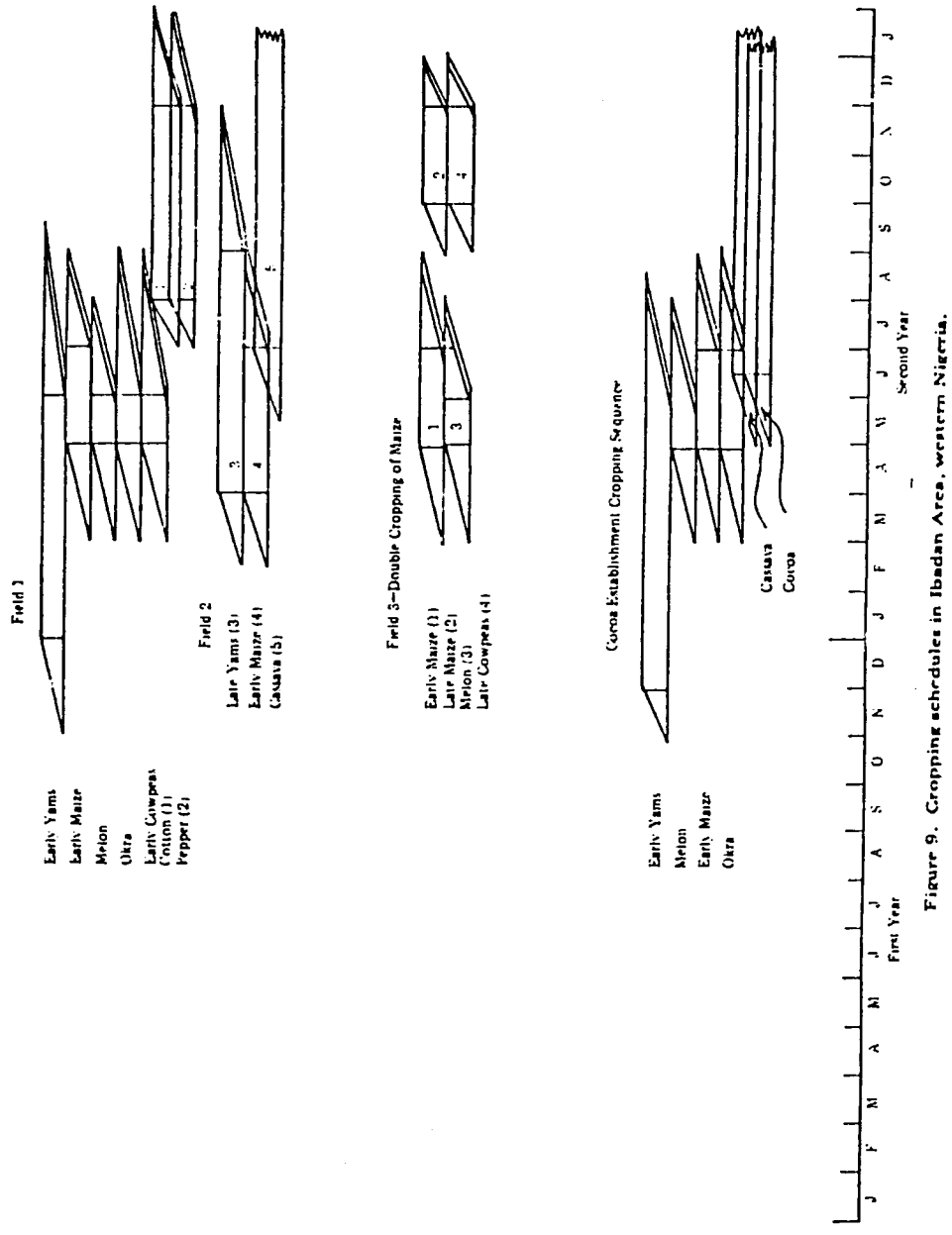


Figure 9. Cropping schedules in Ibadan Area, western Nigeria.

also contains the Jos Plateau with terrace farms and where recently there has developed significant increases in large scale production of subtropical and temperate crops and vegetables for the urban centers of the south. These crops include tomatoes (*Lycopersicon esculentum*), Irish potatoes, and carrots (*Daucus carota* L.). The region is noted for its multiplicity of crops including sorghum, pearl millet (*Pennisetum typhoides*), and two indigenous African grain crops, the hungry rice or acha (*Digitaria exilis* and *D. iburua*) and finger millet (*Eleusine corocana*), yams, cassava and cocoyams in addition to the ancient root and tuber crops risga (*Plectranthus esculentus*) and tumuku (*Solenostemon rotundiflorus*), cotton, sesame (*Sesamum indicum*), indigo (*Indigofera* sp.), soybeans (*Glycine max* L. Merr.), groundnuts, and cowpeas. Other crops include onions (*Allium cepa* L.), rice, sweet potatoes, tobacco (*Nicotiana tabacum* L.), *Capsicum* peppers and henna (*Lawsonia inermis*). Intercropping is a widespread practice.

Netting (1968) studied the Kofyar of the Benue Plateau and details of their cropping systems (Fig. 10). The Kofyar grow at least 30 species of crops in (i) farms, (ii) village gardens close to the continuously farmed homestead gardens, (iii) bush farms lying just outside the settled village perimeter, and (iv) "migrant bush" farms which may be located several hours walk from the village. The homestead farms are permanently cultivated with maize, cocoyams and cowpeas in addition to various subsidiary crops and vegetables. Early millet is often interplanted with sorghum and cowpeas and pumpkins, okra, some maize plants and roselle (*Hibiscus sabdariffa*). Several subsidiary crops such as tobacco, groundnuts, Bambara groundnuts (*Voandzeia subter-*

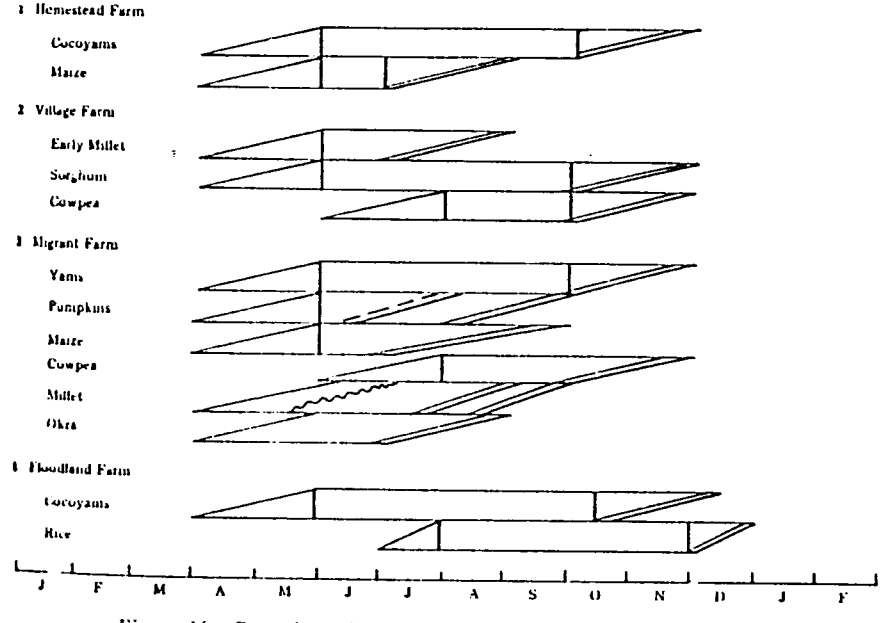
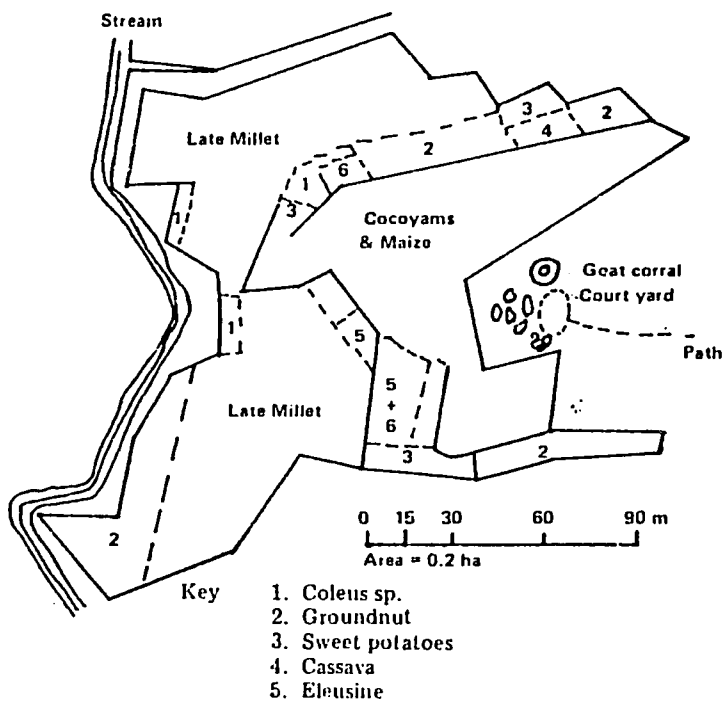


Figure 10. Cropping schedule and combinations of the Kofyar.

ranea) and sweet potatoes are planted on separate plots in different parts of the homestead or village farms. Tree crops such as mangoes, African elemi (*Canarium schweinfurthii*) and papaya (*Carica* sp.) are located near the homestead entrance and may also be dotted about the farms. Details of the planting schedule and patterns of the Bong who live in this area are presented in Figure 11. Average size of farms is about 1 ha, but many are less than 0.5 ha.

NORTHERN NIGERIA

Northern Nigeria stretches from about 10°N to almost 14°N latitude and lies in the semiarid zone of west Africa where the duration of the dry season is over 5 months and the growing season less than 200 days. The major food crops are sorghum and millet while the minor crops are rice, ginger (*Zingiber* sp.), cowpeas, maize, sweet potatoes, yams, pepper, and onions. The main cash crops are groundnuts and cotton.



MIGRANT BUSH FARM ROTATION

1st Year	2nd Year	3rd-8th Year	9th-11th Year	12th Year
Yam	Millet Sorghum Cowpea	Millet Sorghum Cowpea	Cotton or Groundnut	Fallow

Figure 11. Homestead and bush field land use and cropping pattern at Dalung, Bong Beane Plateau (Netting, 1968).

Intercropping is widely practiced. Norman (1974) in a study of intercropping combinations in Zaria Province of the North Central State of Nigeria reported up to 156 different crop mixtures consisting of sole crops, two, three, four, five and six crop mixtures accounting for 16, 42, 23, 12, and 5% of the mixtures, respectively. The seven most frequent mixtures were:

Millet-sorghum (25%)
Millet-sorghum-groundnut-cowpeas (5%)
Millet-sorghum-groundnuts (5%)
Cotton-cowpeas-sweet potatoes (4%)
Cotton-cowpeas (3%)
Millet-sorghum-cowpeas (3%)
Sorghum-groundnuts (2%)

These seven crop combinations covered 61% of the area under the crop mixtures. The areas under sole crops covered 8.4, 3.1, 1.8, and 3.3% of sorghum, cotton, groundnuts, and other crops respectively. Sorghum is the most important food crop and cotton and groundnuts are the most important cash crops.

With the exception of the Kano area and other mixed farm or high population density areas of northern Nigeria, bush fallowing is the common practice with fallow periods ranging from 4 to over 8 years in areas of low population density. Compound farms are common to all areas and are cropped every year with such crops as maize, okra, pepper, roselle, pumpkins, tobacco, and various vegetables. In addition to compound farms and bush fallow fields, there are fadama[3] fields (hydromorphic areas) where bananas, rice, sugarcane, and vegetables are grown. In the flood plains of streams, rice and sugarcane are grown with irrigation. Apart from fruit trees such as mangoes and oranges which are grown in compound gardens, protected plants such as tamarind (*Tamarindus* sp.), locust beans (*Parkia* spp.) and baobab (*Adansonia digitata*) are found dotted about the outlying fields. Where ridges are used, there is usually a definite spatial arrangement of crops with millet occupying the furrow areas while sorghum and cotton are grown on the ridges. Some of the southern crops such as yams and cassava are grown on ridges or mounds. The cassava farms or gardens are usually fenced from other crops for protection against livestock. Some of the mixed cropping schedules used in the area are presented in Figure 12.

Other Countries of West Africa

Various aspects of the cropping systems of west Africa have been reported by Faulkner & Mackie (1933), Allison (1941), Irvine (1969), Porteres (1952, 1955), Johnston (1958), Hardcastle (1959), Guinard (1961), Wills (1962), Bourke (1963), Anyane (1963), Catherinet (1965), De Sapir (1969),

[3] Valley Bottom lands or depressions that are subject to flooding or high water-table in the savanna areas of northern Nigeria. These are often used for the growing of off-season vegetables, bananas and sugarcane.

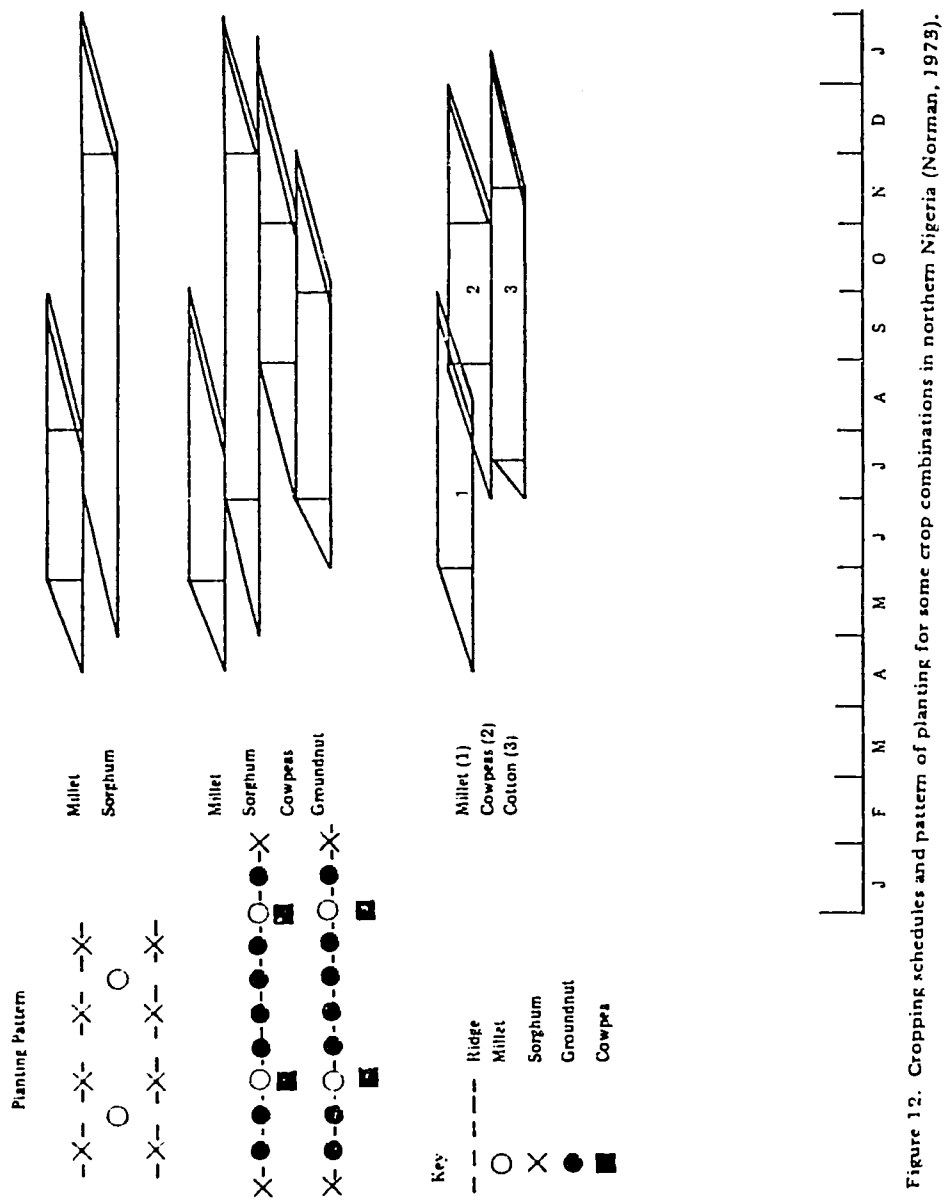


Figure 12. Cropping schedules and pattern of planting for some crop combinations in northern Nigeria (Norman, 1973).

Hartoungh (1969), Kline et al. (1969), Morgan (1969), Morgan & Pugh (1969), Weil (1969), Donald (1970), Grove (1970), Muckle (1971), Thornton (1973), Spencer (1973), Charreau (1974), and Van Santen (1974). Porteres (1955) reported changes in crops grown in parts of Senegal as a result of emergence of groundnuts as a commercial crop. He noted the absence of groundnuts in cropping systems and rotations of Senegal in 1850 and the replacement of seed cotton and sesame by groundnuts in the cropping systems of northern, central, and southern zones of Senegal by 1950, in addition to the inroad made by cassava into the cropping systems of southern Senegal. Charreau (1974) observed that mixed intercropping is widely practiced in the peasant cropping systems in the Francophone countries of west Africa.

Wills (1962) listed various crops grown in compound and outlying farms in parts of Ghana and stressed the increasing importance of market gardening close to urban areas. All the works cited in the preceding paragraph emphasize the widespread practice of mixed intercropping of the kinds found in similar ecological and vegetation zones of Nigeria. Examples of cropping systems which differ somewhat from those of Nigeria include the intensive shallot (*Allium escalonicum*) and vegetable cropping systems of Angola in Ghana (Irvine, 1969, Grove, 1970) and the upland rice intercropping systems of Liberia and Sierra Leone (Fig. 13).

At the edge of the Keta Lagoon, in the Anloga area of Ghana there is an intensive shallot industry involving three crops of shallot in 1 year. The shallot is grown in small patches on beds and vegetables are grown as sole crops or mixtures between the harvesting of one and planting of another shallot crop. The duration of each crop is 6 weeks and tomatoes, okra, maize, and pepper are intercropped with shallot the third crop. The fertility of the alluvial soils on which they are grown is maintained with bat and cow dung, crop residues, fish manure, and household refuse. The shallot farmers usually divide themselves into three groups each of which plants his own shallots 2 weeks after the other to avoid glut in the shallot market. Most of the shallot is sold in Accra.

Van Santen (1974) reported that in the Foya area of Upper Lofa in Liberia upland rice which is planted in May to July is usually intercropped with pepper, bitterball (*Solanum* sp.), beans, maize, bananas, plantains, and cassava. Similarly, Spencer (1973) observed that 91% of the upland rice crop of Sierra Leone is intercropped with cassava, maize, cotton, pigeon peas and/or okra (see examples in Fig. 13).

Central and Southern Africa

Several complex forms of shifting cultivation, bush fallow and semi-permanent farming systems are found in the Congo, northern Rhodesia and adjacent regions in central and southern Africa.

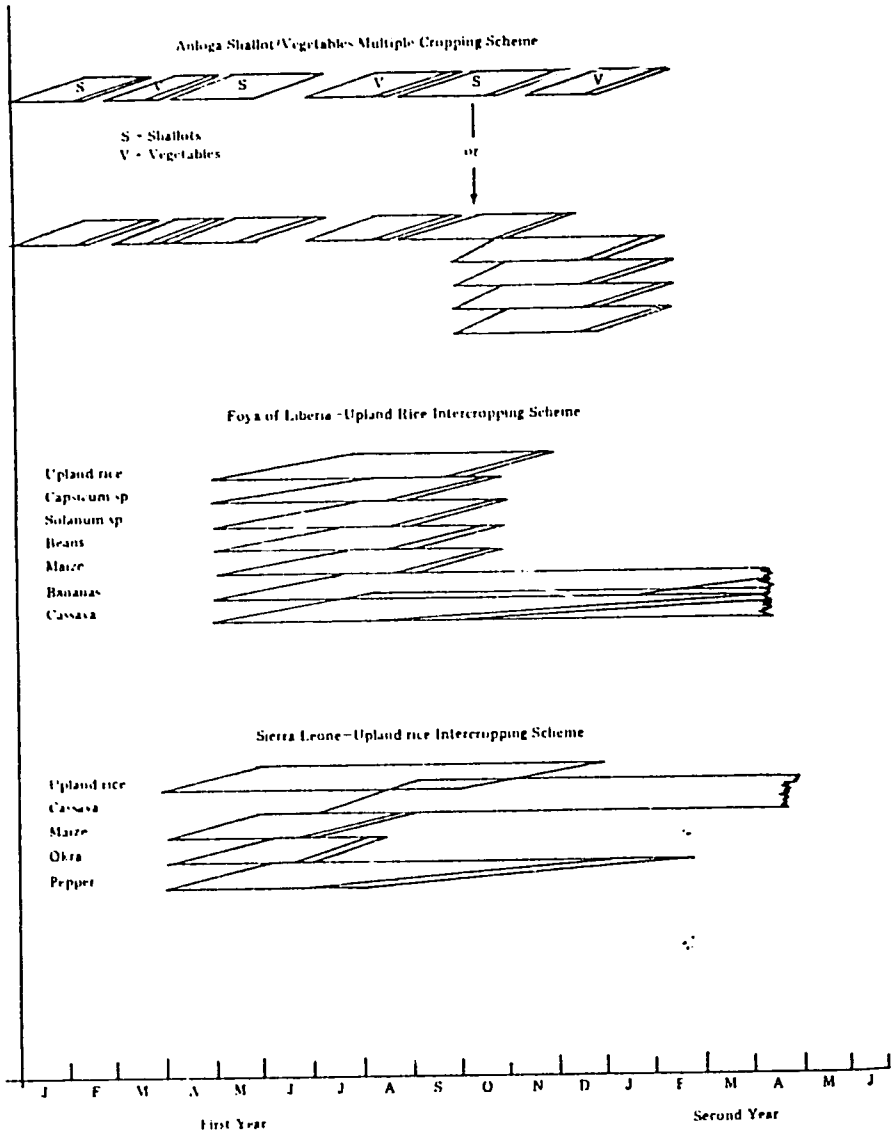


Figure 13. Some multiple cropping schedules of Ghana, Liberia, and Sierra Leone.

THE CONGO

The farming systems of the Congo include bush fallow systems and field types as encountered in west Africa but lower population densities in some areas have resulted in longer periods of fallow than in west Africa. Miracle (1967) identified four major groups of cropping systems in the Congo: classic tropical long fallows, ash fertilizer dependent long fallow systems, compost dependent fallow systems, and short fallow systems. Each of these exhibit variations in terms of sequences of field operations associated with planting.

The Bemba who practice the *chitemene* system clear woodlands 5 to 20 times the area to be cropped, pile the wood and burn it to obtain the ash which is used as fertilizer (Ruthenberg, 1971). Bemba field systems include typical bush fallow field cultivation, anthill cultivation, coleus potato gardens, river gardens, and hutsite gardens (Miracle, 1967; Richards, 1939; Trapnell, 1953). Crop sequences on fields, gardens, and old hutsites are presented in Figure 14. Some of the striking characteristics of these cropping systems include (i) the use of volunteer self-propagated sorghum and groundnuts as components of traditional crop mixtures, (ii) elaborate piling up of wood and trash for burning to obtain ash fertilizer in a system designated as *chitemene* or *citemene*, and (iii) movement of homesteads to facilitate cropping of fertile hutsites. In west Africa, volunteer crops involved in traditional agriculture do not involve major staples but are limited to protected useful tree crops such as the oilpalm and semiwild and indigenous vegetables such as *Corchorus olitorus*, *Ocimum viride* and several species of *Amaranthus*. Reasons for movement of homesteads other than restoration of soil fertility include superstition and witchcraft and reduction of distance between homesteads and fields (Miracle, 1967).

The Azande Cropping System--De Schlippe (1956) and Reining (1970) investigated the agricultural systems of the Azande, the third largest tribe in Congo Kinshasha and small sections of which are also found in the southern Sudan and the Central African Republic. The Azande tackled the short-run problems of decreasing soil fertility by alternation of crops and the long-term by shifting homesteads. As with the Bemba, other reasons given for shifting of homesteads included death of a wife, crop failure due to pest and disease epidemics, and repeated illness suspected to be due to witchcraft. Whenever homesteads were moved, the courtyard gardens were first cultivated before being left to revert to bush by which time the fertility that had been built up during years of human habitation had been almost exhausted. De Schlippe (1956) identified several field types, i.e., (i) the main Eleusine (finger millet) association, (ii) the groundnut Eleusine (finger millet) succession, (iii) Eleusine through grass, (iv) bean patch, (v) ridge cultivation, (vi) maize through sweet potato or sweet potato strip, (vii) maize and oilseed gourd association, and (viii) cassava fallow. In addition to the main field types which are located outside the ridge which defines the outer perimeter of the compound farm or courtyard, there were 11 specialized environments with their special crops. These were: (i) the courtyard on which vegetables, condiment plants, fruit trees, medicinal plants and other useful plants are grown, (ii) the minor ridge in the courtyard on which are grown okra, yams, groundnuts (vegetable), and other vegetables; (iii) old refuse heaps with rice, bananas, cowpea, sesame, maize, etc.; (iv) thatch overhang under the shade of which tobacco nurseries were located; (v) ash accumulations on which tobacco, vegetables, cowpeas, and climbing plants are grown; (vi) living trees used as supports for yams; (vii) termitaria (termite mounds) which were flattened for the produc-

tion of sorghum, rice, and cowpeas; (viii) satellite cultivations located in patches or strips on the borders of fields of main staples; (ix) rubbish heaps in fields on which grow crops requiring higher fertility; (x) spontaneous or volunteer crops; and (xi) valley cultivation beside streams or inside the forest gallery on silt deposited by erosive floods. Some of the above field types, cropping schedules, and associations of the common field types are presented in Figures 15, 16, and 17.

It may be concluded that the cropping systems of the Congo are similar to those of west Africa. Although intercropping is as widespread in the Congo as in west Africa, there is greater dominance of single crops in some of the initial and terminal crop associations. Thus, in the forest zone of the Congo, most crop sequences begin with bananas-plantains and their associations are 44 and 9% of the sequences, respectively, followed by maize (11%) and maize associations (21%). The terminal associations are dominated by cassava (41%), cassava associations (25%), and bananas-plantains associations (16%). In the savanna, initial crop sequences consist of millet-sorghum (16%),

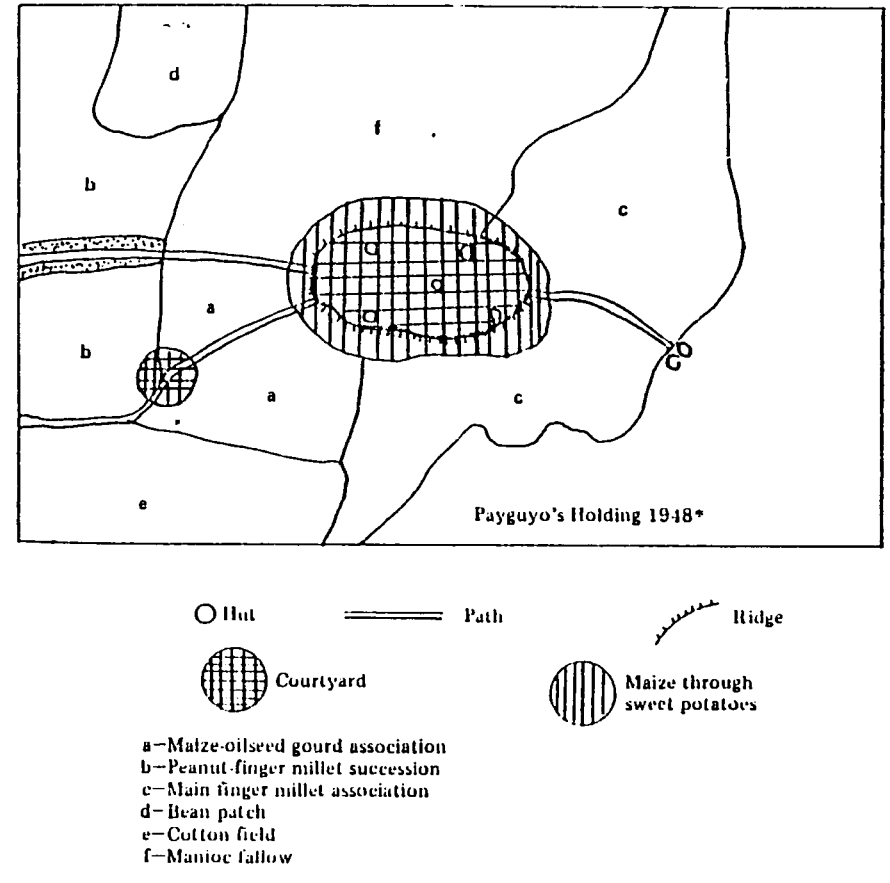
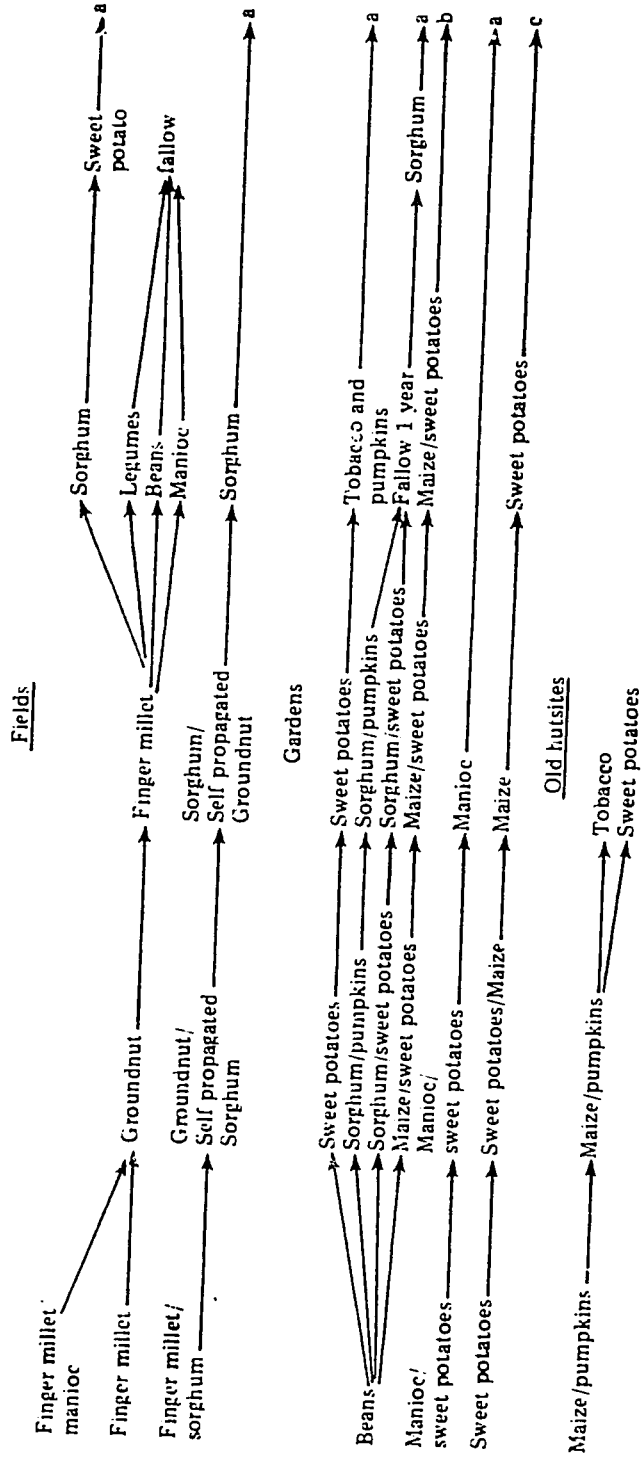


Figure 15. Azande field types (Miracle, 1967).



* Source: Richards (1939) according to Miracle (1967).
a. No information given on what follows
b. Maize and sweet potatoes planted year after year until soil is exhausted, then sweet potato alone as last crop.
c. Maize and pumpkins sown so long as soil is fertile, then tobacco or sweet potatoes.

Figure 14. Bemba crop sequences (Richards, 1939 according to Miracle, 1967).

groundnuts (14%), beans (10%), sweet potato (7%), and cassava associations (19%) as compared to the terminal sequences dominated by cassava (36%) and cassava associations (15%), followed by beans and peas (*Pisum* sp.) (14%) and millet-sorghum (7%). The dominance of cassava in terminal crop sequences in forest areas is similar to the forest zone of west Africa where cassava is usually the last crop before fallow. In most areas of west Africa, annual starchy staples (e.g., maize, yams, and rice) are more likely to dominate the initial crop association than bananas-plantains and their associations

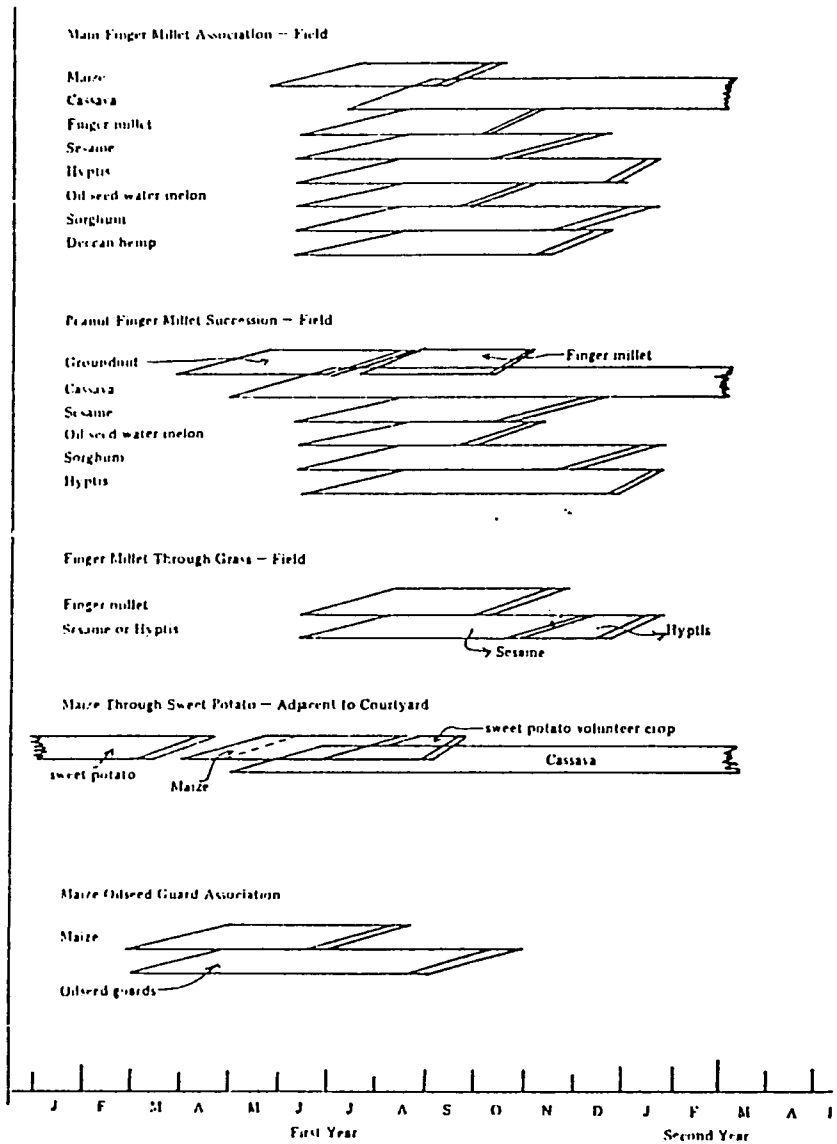


Figure 16. Azande crop associations and cropping schedule.

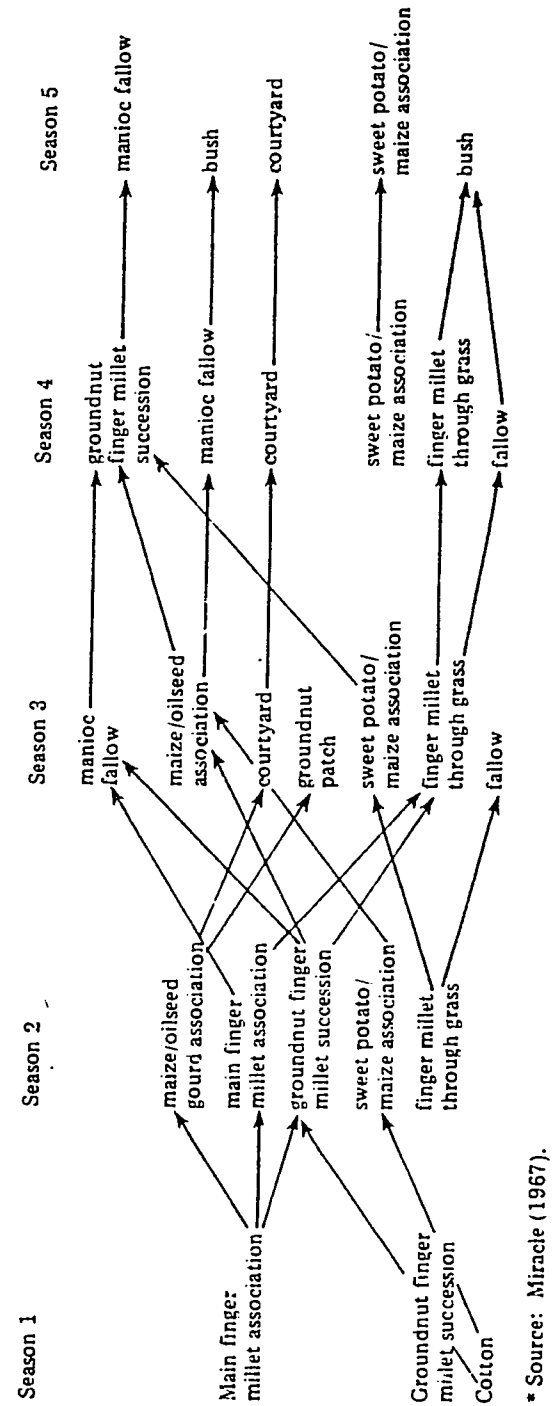


Figure 17. Azande crop sequences (Miracle, 1967).

* Source: Miracle (1967).

as in the Congo basin. In the savanna areas of west Africa, cassava does not attain such dominance of terminal crop associations as in the Congo. However, in both areas there are fewer choices of crops to be grown at the terminal stage of the cropping cycle with its declining soil fertility.

NORTHERN AND SOUTHERN RHODESIA

Allan (1965), Miracle (1967) and Morgan (1969) described the agricultural systems of Zambia, and Yudelman (1964) the agriculture of southern Rhodesia. The agriculture of this area consists of two main systems, i.e., the European and the African systems. The European system involves mechanized large scale farming, with sole cropping and crop rotations. Alienation and reservation of land for Europeans in southern and east Africa prior to recent political developments in Kenya and Tanzania made available to Europeans proportionately more land per capita than for Africans.

African agriculture in this area involves the same *chitemene* shifting cultivation system of the Bemba. Unlike the Bemba who use large ash circles each covering over 0.4 ha, the Lala, Lamba, and Ndembu of northern Rhodesia (Allan, 1965; Miracle, 1967) and some tribes of southern Rhodesia (Yudelman, 1964) employ several small circles (each about 7–11 m in diameter) in place of each large ash circle. Field systems of the small circle *chitemene* are, however, similar to those of the Bemba.

East Africa

East Africa consists of Mozambique, Tanzania, Kenya, Uganda, Ethiopia, and Somalia. Most of these states have large areas of savanna with pastoral peoples who are nomadic and regard crop cultivation as secondary to livestock raising. Consequently, crop production is adapted to a way of life, and it is often the business of women and children. Prior to the advent of land reforms in Kenya and independence of Tanzania and Mozambique, agriculture in this region with the exception of Ethiopia was a dualistic economy consisting of European agriculture and African agriculture. In most of east Africa a wide range of crops can be grown as a result of the prevailing range of elevation from below 500 to 4,000 m. Examples of some of the elevation range of certain crops in Ethiopia reported by Westphal (1975) are in Table 4.

KENYA, UGANDA AND TANZANIA

Acland (1971) reported that although any crop grown in east Africa may be grown in pure culture especially in commercial farms, most have been observed in mixed culture. Examples of mixtures include (i) bananas interplanted with coffee (*Coffea* sp.) in the central province of Kenya, high rainfall areas of Tanzania and with robusta coffee in Uganda; (ii) bananas grown with maize, potatoes, cowpeas, or sugarcane in the central province of

Table 4. Crop adaptation to elevation ranges in Ethiopia (Westphal, 1975)

Crop	Range	Most suitable range
	m above sea level	
Maize	500-2500	500-2000
Finger millet	500-2000	1000-1800
Bullrush millet	500-1600	500-1500
Sorghum	500-2500	500-2000
Tref (Eragrastistef)	1500-2500	1700-2300
Wheat	1500-2500	1700-2400
Groundnut	500-1600	1000-1500
Sesame	500-1500	1000-1300
Cassava	500-2000	1500-1800
Sweet potato	500-2100	1250-2000
Cowpeas	500-2000	1250-1700
Okra	500-1800	1200-1700
Sugar cane	500-2000	1000-1500
Coffee	1200-2400	1500-2000
Banana	500-2000	1500-1700
Mango	500-1700	1100-1600

Kenya; (iii) beans intercropped with maize or cassava; (iv) hyacinth bean (*Dolichos lablab*) intercropped with maize, beans, potatoes, peas, or bananas; (v) bullrush millet (*Pennisetum typhoides*) intercropped with Bambara groundnuts on Ukara Island in Tanzania and with cowpeas, pigeon peas, beans, or maize in the Machakos district of Kenya; (vi) cashew (*Anacardium* sp.) along the southern Kenya coast of east Africa planted at random between coconuts, mango trees, bananas, or cassava; (vii) cassava which is usually the last crop before fallow inter- or relay cropped with sweet potatoes, maize, and beans or sometimes with bananas, yams, and sugarcane on the coastal strip of east Africa; (viii) coconuts intersown with pastures along the coast or planted at wide spacing with bananas, cashew, and mango; (ix) interplanting of coffee with shade trees, e.g., *Albizzia* sp. in Tanzania and *Cordia abyssinica* in Kenya; (x) cowpeas intersown with other food crops or grown for their leaves in patches of pure stands near homesteads; (xi) grams (*Cicer arietinum*) intercropped with cereals, root crops, and other legumes; (xii) pigeon pea relay cropped with finger millet and after millet harvest, intersown with sesame or cowpeas, or intercropped with maize and beans; and (xiii) sisal (*Agava sisalana*) intercropped with beans, maize, cotton, pineapple, or cover crops.

The farming systems of Kenya have undergone changes due to European settlement and introduction of European farming techniques. As a result, traditional cropping systems in Kenya have undergone greater transformation than those of Tanzania and Uganda.

Von Rotenham (1968) reported that mixed cropping was originally widespread in Sukumaland in Tanzania. However, the cultivation of cotton led to considerable amount of sole cropping despite the fact that it was recommended to be grown as a mixed crop in German colonial times. Al-

though sole cropping is common with crops such as rice, only one-third of the area is under mixed cropping. The Wasukuma, for example, practice relay cropping of maize, beans, groundnuts and sweet potatoes. The maize is first planted, and after about 2 weeks, groundnuts and beans are sown in between the maize. After the first weeding, sweet potatoes are added. Crop rotations in several parts of Sukumaland carry both pure cotton and mixed cropping of various kinds according to location and soil type (Table 5).

Ludwig (1968) studied the Wukara permanent cropping system on Ukara Island on Lake Victoria in Tanzania. The first year in a 3-year rotation, bullrush millet is relay intercropped with a late manure crop, *Crotolaria striata*, which is used as green manure for a record crop of early bullrush millet during the second year. The second year bullrush millet is again relay intercropped with late groundnuts and in the third year following harvesting of groundnuts, another early bullrush millet crop is followed by a late crop of sorghum which ends the 3-year cycle. In addition to these crops, the Wukara have developed several permanent cropping systems for different contours or catenas for the valleys on the island and fertility is maintained by the use of organic manures, crop residues, and household refuse.

ETHIOPIA

Westphal (1975) recognized 14 systems of agriculture. Some examples of mixed or intercropping systems are: (i) seed farming complex with absence of vegetables, fruit trees, and shrubs; (ii) seed farming complex where sorghum is dominant with field cropping, home gardening and growing of fruit trees and shrubs; (iii) seed farming complex with sorghum dominant but farming is carried out in well-constructed terraces; (iv) ensat (*Ensete ventricosum*) planting complex with ensat as staple food; and (v) ensat planting complex with ensat as co-staple with cereals and tubers.

Table 5. Examples of crop rotations in Sukumaland (von Rotenham, 1968)

Shinyanga	Black cotton soils and Alluvial soils
1963 Cotton	Maize-sorghum-legume
1962 Cotton	Maize-sorghum-legume
1961 Maize-sorghum-legume	Fallow
1960 Maize-sorghum-legume	Cotton
1959 Cotton	Maize-sorghum-legume
1958 Cotton	Maize-sorghum-legume
Ukerewe	
Sandy to partly loamy soils	**Alluvial soils**
1963 Cassava	Rice-sweet potato
1962 Cassava	Rice-sweet potato-maize
1961 Cassava	Rice-sweet potato
1960 Cotton	Rice-sweet potato
1959 Cotton	Rice-sweet potato
1958 Cassava	Rice-sweet potato-maize

In the Begemdir and Simen area where vegetables and fruits are absent, the common practice is to grow two successive crops in the same field each year (double cropping) with emer (*Triticum dicocum*), barley (*Hordeum vulgare* L.) or lentil (*Lens culinaris*) used as the late crop. Mixed cropping is also practiced with barley and wheat as the most common mixture. Other mixtures include pea and horsebean (*Vicia faba equina*), t'ef (*Eragrostis tef*) and garden cress (*Lepidium sativum*), sorghum and finger millet, sorghum and chick pea, safflower (*Carthamus tinctorius*), and t'ef, sesame and common bean, and maize and gourds (Westphal, 1975).

In Hararge area where field systems, home gardening, and cultivation of shrubs are widely practiced (Westphal, 1975) three cropping zones are encountered, (i) the coffee zone (1,400–1,700 m) with bowl-shaped valleys where there are irrigated banana groves and extensive gardens with mixtures of crops such as coffee, sugarcane, ch'at (*Catha edulis*), maize, sweet potato and t'ef, (ii) durra zone (1,600–2,000 m) where sorghum is the dominant crop with ch'at and coffee at valley bottoms; and (iii) the barley zone (2,000–2,400 m) where barley, wheat, horsebean and peas are grown. In the durra zone 'Gooseneck' sorghum is the most widely grown and is usually planted in mixtures with maize and sometimes, bullrush millet, finger millet, and sesame, with groundnuts and maize or with maize and beans in between. Hararge is the center for ch'at which is usually found between 1,500 and 2,000 m elevation and is commonly intercropped with sorghum, maize, bean, sweet potato, pepper, or coffee. Around the city of Harar, there are orchards of ch'at, coffee, and citrus.

In the sorghum-hoe-terrace complex in Konso area, there are well-constructed terraces supporting an intensive agriculture involving permanently cultivated and regularly manured land surrounding the villages. Away from the villages a fallow system without cultivation is used to maintain soil fertility. Crops grown in this area in mixed culture include maize, pulses, tuber crops, linseed (*Linum* sp.), sunflower (*Helianthus* sp.) and cotton. Pure cotton occurs in periphery of settlements and yams are grown as single plants in gardens near terrace walls. Sorghum is nearly always broadcast with finger millet. Usually the first crop in the mixture to be planted are cormels of *Araceae* which are then followed by cotton, cereals, and pulses before the seeds are covered with soil. Wheat and barley in the zone between 1,700 and 2,000 m are sown in mixed stands. To minimize competition, sowing is done when other crops are about 10 cm high.

The ensat planting complex in which ensat is the main food source is found among the Gurage, Sidamo, and other peoples in the southeastern part of the Ethiopia highlands in the Rift Valley and in the eastern Sidamo Highlands (Westphal, 1975). The Sidamo, who live south of Lake Awasa, grow large plantations of ensat in addition to coffee gardens. Ensat is planted in age classes on previously cropped land near the homestead and only near huts are age classes mixed. The ensat is often mixed with coffee and sometimes interplanted with a legume (*Erythrina sp.*). Part of the homestead garden carries small irregular patches of wheat, barley, t'ef, and pea. Outside the home-

stead gardens, maize, sorghum, and t'ef and sometimes wheat and barley are grown during the cropping cycle after the fallow. In the ensat area, there are different elevation zones for (i) coffee (1,800–2,000 m), where small patches of t'ef, wheat, taro, beans (in mixed culture), sweet potatoes, and tobacco are grown; (ii) wheat-pulse (2,000–2,500 m) where maize, sorghum, and coffee decrease and wheat, barley, and horsebean appear; and (iii) in the upper ensat and barley (2,400–2,500 to 3,000 m), where barley, cabbage (*Brassica* sp.) and ensat near huts are important.

In the ensat co-staple area with cereals and tubers, the Wollamo inhabit the area north of Lake Abaya. There is a regular planting pattern and patch intercropping is common. There is an almost fixed pattern around the homestead especially in eastern Wollamo. The exit to huts always leads to an ensat plantation. Planted on both sides of the entrance are cabbage, tobacco, pepper, and other spices. Behind the hut, is the first semicircle of coffee shrubs and in areas above 1,600 m a small ensat plantation. Then the field with mixtures of maize, sorghum, beans, and cabbage follow. Various remote parts are occupied by pure stands of wheat, barley, pulses, and tuber crops.

REVIEW OF RESEARCH ON INTERCROPPING IN AFRICA

As far back as 1934 Leakey (L. S. B. Leakey and C. L. A. Leakey, 1970. Science and the African. Re-edition of a paper by L. S. B. Leakey, 1934.) emphasized that more priority should be given to research in the indigenous methods of food production than to cash crops because of advantages of mixed cropping. Although several studies in east Africa were devoted to intercropping and relay cropping as reported by Chaundy (1939), Sturdy (1939), Briant and Johns (1940), Nye (1940), Robertson (1941), Edwards (1941), Watson (1941), Evans (1960, 1962), and Grimes (1963). Interest lagged until Osiru and Willey (1972), Willey and Osiru (1972), and Enyi (1972, 1973) reported results of recent work. In Nigeria, Faulkner and Mackie (1933) reported the widespread practice of intercropping and the reluctance of farmers to abandon the practice. Some of the early rotations started on students' farm in Moor Plantation involved intercropping and double cropping (F. A. Dada, 1974. Agronomics analysis of crop rotation management in the School of Agriculture. Moor Plantation, Ibadan. IRAT, Unife, M. P. Ibadan. Mimeo, p. 1-11). Favorable results of temporary intercropping of oilpalms for the first few years during plantation establishment were reported by Sparnaaij (1957). Since 1964 socio-economic studies of traditional farming systems were initiated at the Institute of Agricultural Research in Samaru later followed by intercropping agronomic investigations (Norman, 1968, 1973a, b, 1974; Baker, 1974; Andrews, 1974, 1975; Kassam & Stockinger, 1973; D. W. Norman, 1973. Incorporating the time dimension: The case of crop mixtures in N. Nigeria. Multiple Cropping Workshop, IRDC and IRRI, Philippines. Mimeo; B. J. Buntjer, 1970. Aspects of the Hausa system of cultivation. IAR, Samaru. Mimeo; D. J. Andrews, 1970.

Relay and intercropping with sorghum at Samaru. Ford Foundation/IITA/IRAT Conference on mixed cropping, Ibadan, Nov. 1970. Mimeo, p. 1–12).

CONCLUSIONS

The above review of traditional cropping systems in Africa indicate that:

1. Multiple cropping systems are part of traditional farming in Africa.
2. The most widespread cropping system in Africa consists of mixed intercropping in compound farms which forms a complex but stable agroecosystem.
3. Intercropping involving small patches of a few pure stands of crops at varying distances from each other in addition to relay cropping are also more common than successive cropping sequences.
4. Traditional cropping systems involve many field types and elaborate compound farm system components which are designed to take advantage of various environmental situations or topographic features on the farms.

Research and observations on mixed cropping, patch intercropping and relay cropping systems in Africa indicate that:

1. The traditional farmer practices intercropping because it gives higher total yields and greater returns than the same crops grown in pure culture.
2. Because of minimized pest and disease losses and losses due to adverse environmental conditions, risk is lower in intercropping than sole cropping.
3. Investigations in intercropping should include:
   a. plant populations of the component crops
   b. length of the cropping season
   c. plant structure (height, canopy structure, rooting systems)
   d. relative duration of the life cycles of the component crops
   e. nutrient requirements
   f. planting patterns
   g. soil fertility
4. According to Wrigley (1969) and other research, the overall advantages of intercropping include:
   a. increased erosion protection
   b. insurance against crop failure
   c. labor and harvesting are spread more evenly during the cropping season and storage problems may be minimized
   d. locations are found for crops required in small quantities, for a range of products, and facilitating production of many commodities in a limited area
   e. it results in efficient utilization of resources by plants of different heights, rooting systems, and nutrient requirements
   f. where legumes are grown with grasses, grasses may benefit from the nitrogen fixed by the companion crop
   g. diseases and pests do not spread rapidly in mixed culture as in pure culture since all crops involved are not susceptible to the same extent

5. Disadvantages of intercropping include:
   a. Mechanization planting and harvesting is difficult
   b. It is more difficult to apply improved inputs, e.g., fertilizers and herbicides as in sole cropping
   c. Experimentation with intercropping is more complex and difficult to manage than with sole cropping.

At present, increased priority is being given to research on multiple cropping in tropical Africa at the Institute of Agricultural Research (IAR), Samaru, Zaria; the International Institute of Tropical Agriculture at Ibadan (IITA); and various institutions of higher learning, especially at the Universities of Tanzania (Moregoro), Makerere, Ibadan, Ife, Ile-Ife, and Nigeria.

LITERATURE CITED

Acland, J. D. 1971. East African Crops, Longmans Group, London.

Allan, W. 1965. The African Husbandman, Oliver & Boyd, Edinburg.

Allison, P. A. 1941. From Farm to Forest. Farm Forest 2(2):95-98.

Andrews, D. J. 1974. Responses of sorghum to intercropping. Exp. Agric. 10:57-63.

Andrews, D. J. 1975. Intercropping with sorghum. *In* N. G. P. Rao and L. R. House (ed.) Sorghum in the 70's. Oxford & IBH Publishing Co., New Delhi.

Anyane, S. L. 1963. Ghana Agriculture, Oxford University Press, London.

Baker, E. F. I. 1974. Research into intercropping aspects of farming systems in Nigeria. Mixed cropping with cereals: A system for improvement. p. 287-301. *In* Proceedings of the Farming Systems Workshop. ICRISAT, Hyderabad, India.

Benneh, G. 1972. Systems of agriculture in tropical agriculture. Econ. Geogr. 48(3): 245-257.

Boserup, T. P. 1970. The conditions of agricultural growth. Allen and Unwin, London.

Bourke, O. O. D. 1963. The West African millet crop. Afr. Soils VIII(1):121-132.

Briant, A. R., and R. Johns. 1940. Cassava investigations in Zanzibar. E. Afr. Agric. For. J. 5:401-412.

Catherinet, M. 1965. Note Sur la Culture du Macabo et du taro an Cameroun. Agronomie Tropicale 20(8):717-724.

Charreau, C. 1974. Systems of cropping in the dry tropical zone of west Africa with special reference to Senegal. p. 443-468. *In* Proceedings of the Farming Systems Workshop. ICRISAT, Hyderabad, India.

Chaundy, G. N. 1939. Primitive agricultural methods of the West Suk Tribe and some improvements. E. Afr. Agric. For. J. 5:23-30.

De Sapir, O. L. 1969. Agriculture and Diola society. p. 192-227. *In* P. F. M. McLoughlin (ed.) African food production systems: cases and theory. The Johns Hopkins University Press, Baltimore.

Donald, Leland. 1970. Food production by the Yalunka household Sierra Leone. p. 165-191. *In* P. F. M. McLoughlin (ed.) African food production systems cases and theory. The John Hopkins Univ. Press, Baltimore.

Duckham, A. N., and G. B. Masefield. 1971. Farming systems of the world. Chatto and Windus, London.

Dumont, R. 1970. Types of rural economy: Studies in world agriculture. Methuen and Co., Ltd., London.

Edwards, D. C. 1941. Possibility of establishment of grass under maize. E. Afr. Agric. For. J. 6:233-235.

Enyi, B. A. C. 1972. Effects of intercropping maize or sorghum with cowpeas, pigeon peas or beans. Exp. Agric. 9:83-90.

Enyi, B. A. C. 1973. Effects of intercropping maize or sorghum with cowpeas, pigeon peas or beans. Exp. Agric. 9(1):83-90.

Evans, A. C. 1960. Studies in intercropping. E. Afr. Agric. For. J. 26:1-10.

Evans, A. C. 1962. Soil fertility studies in Tanganyika III: On the Kikuyu and Lusoni soil types of the lake and western regions. E. Afr. Agric. For. J. 28:231-239.

Evenson, J. P., D. L. Plucknett, and I. Horton. 1973. A proposed classification for agricultural systems. p. 63-69. *In* Proceedings Second International Symposium on Tropical Root and Tuber Crops. 23-30 Aug. 1970. Honolulu. Vol. II.

Faulkner, O. J., and J. R. Mackie. 1933. West African agriculture. Cambridge University Press, London.

Federal Office of Statistics. 1972. Nigeria rural economic survey consolidated report of crop estimation 1968/69 to 1970/71, Agriculture Statistic Unit. FOS, Lagos.

Floyd, B. 1969. Eastern Nigeria. A geographical review. MacMillan, London.

Greenland, D. J. 1974. Evolution and development of different types of shifting cultivation. Regional Seminar on Shifting Cultivation and Soil Conservation. W. Africa. Soils Bull. No. 24. p. 5-13. FAO, Rome.

Grigg, D. B. 1974. The agricultural systems of the world: An evolutionary approach. Cambridge University Press, London.

Grimes, R. C. 1963. Intercropping and alternate cropping of cotton and maize. E. Afr. Agric. For. J. 28:161-163.

Grove, A. T. 1970. Africa south of the Sahara. Oxford University Press, London.

Guinard, A. 1961. Le Systeme Cultural de la region de Man (Cote d'Ivoire) Agronomie Tropicale XVI(2):148-178.

Hardcastle, J. E. Y. 1959. Development of rice production and research in Nigeria Trop. Agriculture Trin. 36(2):79-95.

Hartoungh, Ir J. C. C. 1969. Problems of development in Ogoni. World Crops 21(3): 182-185.

Irvine, F. R. 1969. West African agriculture. Vol. 2. Oxford University Press, London.

Jameson, J. D. (ed.). 1970. Agriculture in Uganda Uganda Government Min. of Agriculture and Forestry. Oxford University Press, London.

Jarret, H. R. 1966. An outline geography of Africa, 2nd Edition. Methuen and Co., Ltd., London.

Johnston, B. F. 1958. The staple food economics of western tropical Africa. Stanford University Press, Stanford.

Jones, W. O. 1965. Environment, technical knowledge and economic development in Tropical Africa. p. 29-48. *In* D. Brokensha (ed.) Ecology and economic development in Tropical Africa. Institute of International Studies. Res. Series No. 9, University of California, Berkeley.

Kassam, A. H., and K. R. Stockinger. 1973. Growth and nitrogen uptake of sorghum and millet in mixed cropping. Samaru Agric. Newsl. 15(1):28-32.

Kimble, G. H. T. 1962. Tropical Africa Vol. 1: Land and Livelihood. Doubleday & Co. Inc. Garden City, New York.

Kimble, G. H. T., and R. Steel. 1966. Tropical Africa today. Webster Division, McGraw Hall Book Co., St. Louis.

Kline, C. K., D. A. G. Green, R. L. Donahue, and B. A. Stout. 1969. Agricultural mechanization in equatorial Africa. Institute of International Agriculture Research Report No. 6, Michigan State University, East Lansing.

Laut, P. 1971. Agricultural geography. Vol. 1. Thomas Nelson, Sydney, Aust.

Ludwig, H. D. 1968. Permanent cropping on Ukara: The impact of land shortage on husbandry practices. p. 87-135. *In* H. Ruthenberg (ed.) Smallholder farming and smallholder development in Tanzania, Munich: IFO Institute for Economic Studies. African Studies No. 24.

Matheson, J. K., and E. W. Bovril (ed.). 1950. East African agriculture: A short survey of the agriculture of Kenya. Uganda, etc. Oxford University Press, London.

Miracle, M. P. 1967. Agriculture in the Congo Basin. University of Wisconsin Press, Madison.

Morgan, W. B. 1959a. Agriculture in southern Nigeria. Econ. Geogr. 35:138-150.

Morgan, W. B. 1959b. The influence of European contact on the landscape of southern Nigeria. Geogr. J. 125:48-64.

Morgan, W. B. 1969. Peasant agriculture in tropical Africa. p. 241-272. *In* M. F. Thomas and G. W. Whittington (ed.) Environment and land use in Africa. Methuen and Co., Ltd., London.

Morgan, W. B., and J. C. Pugh. 1969. West Africa. Methuen and Co., Ltd., London.

Muckle, F. B. 1971. Farming in Sierra Leone. Agriculture, Vol. 78(4):171-174.

Netting, R. McC. 1968. Hill farms of Nigeria. University of Washington Press, Seattle.

Norman, D. W. 1968. Why practice intercropping? Samaru Agric. Newsl. 10(4):107-116.

Norman, D. W. 1973a. Crop mixtures under indigenous conditions in northern part of Nigeria. p. 130-144. *In* I. M. Ofori (ed.) Factors of agricultural growth in West Africa. Proceeding of the International Conferences, Legon April 1971, Accra. Institute of Social and Economic Research, University of Ghana.

Norman, D. W. 1973b. Economic analysis of agricultural production and labour utilization among the Hausa in the north of Nigeria. Samaru Research Bulletin 191, IAR, Ahmadu Bello University, Zaria.

Norman, D. W. 1974. Rationalizing mixed cropping under indigenous conditions: The example of northern Nigeria. J. Development Studies II(1):3-21.

Nye, G. W. 1940. Some results from Bukalasa Experiment Station Uganda. Part 1: General. E. Afr. Agric. J. 5:460-465.

Osiru, D. S. O., and R. W. Willey. 1972. Studies on mixtures of dwarf sorghum and beans. J. Agric. Sci. Camb. 79:531-540.

Porteres, R. 1952. Linear cultural sequences in primitive systems of agriculture in Africa and their significance. Afr. Soils II(1):15-29.

Porteres, R. 1955. Agricultural crisis in Senegal. Afr. Soils III(1):41-51.

Porteres, R. 1962. Primary cradles of agriculture in the African continent. p. 43-58. *In* J.D. Fage and R. A. Oliver (ed.). 1970. Papers in African Prehistory, Cambridge University Press, London.

Reining, P. 1970. Social factors and food production in an east African peasant society: The Haya. p. 41-89. *In* P. F. M. McLoughlin (ed.) African food production systems: cases and theory. The John Hopkins Press, Baltimore.

Richards, A. 1939. Land, labour and diet in northern Rhodesia. Oxford University Press, London.

Robertson, J. K. 1941. Mixed or multiple cropping in native agricultural practice. E. Afr. Agric. For. J. 6:228.

Ruthenberg, Hans. 1971. Farming systems of the tropics. Oxford University Press, London.

Ruthenberg, Hans. 1974. Agricultural aspects of shifting cultivation. FAO, Regional Seminar on Shifting Cultivation in Africa, Ibadan. FAO/SIDE/ARCN Soil Bull. No. 24. p. 99-112, FAO, Rome.

Schlippe, P., de. 1956. Shifting cultivation in Africa. The Land Systems, Routoledge and Kegan, London.

Shaw, T. 1972. Early agriculture in Africa. J. Historical Soc. of Nigeria VI(2):144-192.

Sparnaaij, L. D. 1957. Mixed cropping in palm cultivation. J. West Afr. Inst. Oil Palm Research 2(7):244-264.

Spencer, D. S. C. 1973. Rice production and marketing in Sierra Leone. p. 130-144. *In* I. M. Ofori (ed.) Factors of agricultural growth in west Africa. Proceeding of the International Conference, Legon April 1971. Accra. Institute of Social and Economic Research, University of Ghana.

Sturdy, D. 1939. Leguminous crops in native agricultural practice. E. Afr. Agric. For. J. 5:31-32.

Thornton, D. S. 1973. Agriculture in southeast Ghana. Vol. 1. Summary Report, Development Study No. 12, University of Reading, Dep. of Agric. Econ. and Management, Reading.

Trapnell, C. G. 1953. The soils, vegetation and agriculture of northeastern Rhodesia, Report of the Ecological Survey, Lusaka.

Upton, M. 1967. Agriculture in southwestern Nigeria. Development Studies No. 3, University of Reading, Dep. of Agric. Economics, Reading.

Uzozie, I. C. 1971. Patterns of crop combination in the three eastern states of Nigeria. J. of Tropic. Geogr. 33:62-67.

Van Santen, C. E. 1974. Farm management and production economy. Papers I-VI Republic of Liberia, Ministry of Agricultural Development of Rice Cultivation Project in Liberia UNDP/SF/FAO/LIR/70/505.

Von Rotenham, D. 1968. Cash cropping in Sukumaland. p. 87-135. *In* H. Ruthenberg (ed.) Smallholder farming and smallholder development in Tanzania. Munich. IFO Institute for Economic Studies. African Studies No. 24.

Watson, J. M. 1941. Some aspects of Teso agriculture. Afr. Agric. J. 6:207-212.

Weil, P. M. 1969. The introduction of the ox plow in central Gambai. p. 229-263. *In* P. F. M. McLoughlin (ed.) African food production systems: cases and theory. Johns Hopkins University Press, Baltimore.

Westphal, E. 1975. Agricultural systems in Ethiopia. Agricultural Research Report No. 826 College of Agriculture Hail Sellassie I University and Agriculture University of Wageningen, Centre for Agric. Publishing and Documentation.

Whittlesey, D. 1962. Major agricultural regions of the earth. p. 416-444. *In* P. L. Wagner and M. V. Mikesell (ed.). 1962. Readings in cultural geography. The University of Chicago Press, Chicago.

Wills, J. B. 1962. The general pattern of land use. p. 210-225. *In* J. B. Wills (ed.) Agriculture and land use in Ghana, Oxford University Press, London.

Willey, R. W., and D. S. O. Osiru. 1972. Studies on mixtures of maize and beans (*Phaseolus vulgaris*) with particular reference to plant population. J. Agric. Sci. Camb. 79:517-529.

Wrigley, G. 1969. Tropical agriculture: the development of production. Faber and Faber, London.

Yudelman, M. 1964. Africans on the land economic problem of African agricultural development in southern, central and east Africa with special reference to southern Rhodesia. Harvard University Press, Cambridge Mass.

Fauck, R. 1977. Soil erosion in the Sahelian zone of Africa: Its control and its effect on agricultural production. From Proceedings of an International Symposium on Rainfed Agriculture in Semi-arid Regions, G.H. Cannell, ed. University of California and Oregon State University, April 17-22.

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SUMMARY

Those features particular to Sahelian soils which determine erodibility are discussed. Mean wind and water sensitivity are given for the major categories of Sahelian soils in three classifications. Qualitative and quantitative data for forms and degrees of erosion are given as determined by various methods (runoff plots, rain simulator). They are complemented by theoretical evaluations using the Fournier and Wischmeier formulae. The values for the R, K, C, and P terms of the Wischmeier equation give a good estimation of the average soil losses in various situations comparative to data obtained in the USA and show the strong erosive potential of rainfall in semi-arid regions.

The effects of erosion on crop yields and on the productivity of pasture land are analyzed. The distinction is made between the effects of runoff and those of erosion. Runoff decreases infiltration, modifies the soil water balance and increases aridity. Loss in potential soil fertility is caused by the decrease in water available in the soil, by the shortening of the growth period, and by soil losses caused by water and wind erosion.

Wind erosion control must involve restricting overgrazing, which is a socio-economic and political problem as much as a technical one. Setting aside protected areas is a very effective practice, but it is of limited use. Surface tillage practices prove effective in the regeneration of certain grazing lands.

The C factor is the most important term in the Wischmeier equation. With the exception of the most basic ones using stones, mechanical practices (contour plowing) are not suitable in the Sahel zone.

All soil tillage practices have increased infiltration as their basic goal. Biologic methods (crop residues, mulching combined with

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undisturbed residues of volunteer vegetation) control erosion most effectively.

The conclusions concern the need to promote the integrated management of the Sahelian region on ecological bases -- erosion problems being but one aspect of a balanced ecosystem. This management must be adapted to the specific conditions of the very diverse Sahelian region, and they must deal with the probability of future periods of exceptional dryness.

GENERALIZATIONS

The Sahelian region is situated between the desert zone and the Sudanian zone in Africa south of the Sahara. The northern and southern boundaries are only approximate because the area constantly changes. Besides there are many varying geographic definitions of the Sahel. It is the climatic characterization which is of interest here. This is a region where a 2-4 month monsoon rainy season alternates with a long 8-10 month dry season. The annual potential evapotranspiration of more than 2 meters always exceeds the rainfall. The isohyet limits are 100 mm and 650-750 mm -- but these values are very theoretical when the irregularity of the rainfall is considered not just in time, but also in space (Rijks, 1971). Moreover, there are few meteorologic stations and the determination of the isohyets is only approximate. Some distinguish two sub-regions, the Sahel of the nomads between 250 and 650 or 700 mm depending on the country. This geographic zone represents a band that crosses northern Senegal, Mauritania, central Mali, northernmost Upper Volta, Niger, Chad, northern Cameroon, northern and central Sudan, and some parts of Ethiopia and Somalia. The Cape Verde Islands and eastern Gambia should be included in this list. In many of these countries the official boundary of the Sahel is often set back to 800 mm and even 850 mm average annual rainfall.

The word "Sahel" actually corresponds to very variable ecosystems: from islands to extremely inland countries, with or without major river systems, located on sedimentary or crystalline geologic rocks sometimes involving very diverse soils, and the concept of the isohyet proves to be an inadequate way to characterize its boundaries. Aridity is the only thing common to all the ecosystems.

Between 1968 and 1973 these countries underwent a period of exceptional dryness. The rainfall was 20-50% below average. This substantial increase in aridity had social and economic, as well as biologic consequences (Billa, 1974). The impact of the drought was also apparent in soil fertility and particularly showed up in an increase in erosion. The initial cause was the serious modification in the density

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of plant cover caused by the decreased water supply. Overgrazing of the herbaceous ground cover and shrubs increased the destruction of the plant cover. It is often hunger and not thirst that has caused the high mortality rate in cows, sheep and goats. Besides stripping the soil by overgrazing, excessive trampling due to the concentration of herds around water sources, wells, temporary ponds or permanent waterholes caused degradation of the structure of the upper horizons of certain soils. These soils have, then, become very vulnerable not only to wind erosion but also to erosion caused by runoff.

After each dry season, the rains, no matter how many, always fall at the beginning of the rainy season in the form of tornadoes with high intensities. Falling on land without plant cover, with a surface horizon disturbed by overgrazing or trampling, these rains cause intense runoff reaching erosive intensity in many places and causing substantial soil loss. Later, during the new dry season, wind can carry off the finest soil particles because the vegetation no longer creates an obstacle and the soils have lost their surface cohesiveness.

In these circumstances the combined effects of wind and runoff erosion (which are normally processes affecting different kinds of soils) have, in certain cases, and on the same soils, caused substantial damage.

Much information on the effects of drought has been disseminated throughout the world and the term "desertification" has been used (Boudet, 1972; CTFT, 1973; Le Houerou, 1973; Monod, 1973). The United Nations organized a general conference with "desertification" as its theme which took place in August 1977 in Nairobi. The FAO and UNESCO have been entrusted with the creation of a world map of small scale desertification.

This paper will be limited to an attempt to evaluate the present state of our knowledge of the risks of erosion in the Sahel. These risks are dependent on climatic data, on topographic conditions, but also on the particular characteristics of the soils. The role of these characteristics will be examined first and the discussion will be limited only to those groups of soils used for rainfed cultivation. In practice it is these groups which are most affected by the erosive phenomena.

THE GENERAL CHARACTERISTICS OF SAHELIAN SOILS WHICH DETERMINE THEIR ERODIBILITY

"Climatic aridity" distinguishes the morphology of the Sahelian soils and gives them a certain number of common characteristics (Aubert, 1961; Berry, 1974). The characteristics of non-flooded or waterlogged soil types are less depth, often large amounts of sand,

very evolved but insufficient organic matter, poorly developed structure to weak stability, relatively high rate of saturation in bases, soluble elements either concentrated on the surface or at a slight depth (Dabin, Fauck and Pias, 1967). A water regime characterized by an annual potential evapotranspiration greater than the total rainfall and high temperatures with important surface variations must be included in the list. The hydrologic balances vary though according to the soil's topographic position and morphologic characteristics.

The various classifications or legends having a worldwide scope use these various common characteristics to define their upper levels. Thus in the FAO legends the yermosols, xerosols, regosols, and arenosols are distinguished by the combination of the following criteria: water regime, ochric horizon, presence or lack of cambic, argillic, calcic, gypsic horizons. These are the same basic criteria which are used in Soil Taxonomy (aridisols, torr and ust suborders, ochric groups, lithic sub-groups etc., Dregne, 1976). The two systems of utilization of the particular sandy texture which gives soils their specific natures (arenosols, psamments) need to be added. The current French classification relies on the concept of evolution in relation to the mother rock (raw mineral soils, slightly evolved soils), on ionic dominance (calcomagnesimorphic soils), on the distribution of organic matter and the rate of saturation of their complex (isohumic soils). The sub-classes are defined either by climatic data or granulometric data (lithosols and regosols). The three systems, though, are in harmony when it comes to the use and definition of the term "vertisol" at the upper level of each of the classifications.

However, when it is a question of susceptibility to water or wind erosion, none of the legends or classifications, at least on the upper levels used in the case of small scale maps, give any certain way of defining erodibility. The characteristics which determine this erodibility are:

- the texture of the surface horizon: the amount of sand with varying granulometry (for wind erosion), amount of colloids (for runoff);

- the quality of the surface structure, in particular the amount of aggregates smaller than 0.84 mm., the stability of this structure with an idea of their resistance to degradation caused by trampling by the herds or the passage of machines, and especially the tendency to form a fine surface crust with a loss of porosity. The quality of the structure is also determined by the presence of certain ions (sodium) on the complex. In certain cases algae and micro-organisms have modified the surface structure (biological deposits).

- the permeability of the upper horizon which is conditioned by the texture and the structure, and especially the evolution of speed of permeability in time (rate of runoff).

- amount and forms of calcium carbonates. They affect the structure and permeability, but their calcic rocks are very rare in the Sahel.

- the clay's minerologic type: the 1/1 clays generally give unstable structures in the semi-arid climates, the 2/1 clays, because they can swell, often lead to gullying. To simplify things, the characteristics used in the upper levels of the classifications only permit the evaluation of certain aspects of the theoretic risk of erosion by using major textural distinctions like psamments, regosols, lithosols. But in practice erodibility can only be safely defined at classification levels which permit better determination of the textural classes and the quality of the structure of the surface horizon. This most often occurs at the level of the family (Soil Taxonomy, French classification). With the FAO legend (1976) the use of "phases" means improvement. The phases are subdivisions of soil units based on characteristics which are important in land use or management but which have no diagnostic value when it comes to the separation of the soil units themselves. Moreover, the definition of these phases corresponds to those formulated in Soil Taxonomy, but they have the advantage of being shown on small scale maps (1/5 million, FAO, UNESCO, 1974).

Table No. 1 gives a qualitative evaluation of the erodibility of the main Sahelian soils with an attempt made to correlate the three classifications and to name the soils. It is based on the interpretation of data supplied by pedologic studies done in the Sahel (Audry and Rossetti, 1962; Gavaud, 1968; Dabin, 1969; Boulet et al., 1971). The descriptions and the analyses available allow definition of the most common textural classes and determination of the clayey minerals. Generally speaking the kaolinitic clays are mainly found in the sandy or sandy-clayey soils which have developed on aeolian drift, on ancient sedimentary rocks, on alluvial material. The presence of type 2/1 clays is almost completely limited to the cases of soils on recent alterations of granitic or basic metamorphic rocks and on ancient, often indurated alterations marked by more humid paleoclimates (Fauck 1967).

Observations by soil scientists also show the structural characteristics specific to certain kinds of widely distributed soils. Thus the alkalized subarid brown soils and the tropical ferruginous soils (French classification) have a definite tendency to seal at the beginning of the dry season. With the brown soils having a sandy-clayey texture it was found that the profile stayed dry in depth during part of the rainy season. This shows that the relative impermeability of the two upper centimeters limited infiltration (shays decrease of hydraulic conductivities) and caused the runoff of most of the high intensity rains at the beginning of the rainy season. In this case, then, the

TABLE 1. The Erosiveness of the Main Sahelian Soils (Rainfed Agriculture)

French Classification	Soil Taxonomy	FAO Legend	Wind Erosion	Water Erosion	Comments
Raw mineral soils -lithosols -regosols	lithic sub-groups of many orders orthents or psamments	lithosols regosols	slight variable	slight slight	high run off depends on texture
Slightly evolved soils -sub-desert grays -lithic soils -regosolic soils	aridisols lithic sub-groups entisols (torripsamments & torriorthents) aridisols (calciorthids)	xerosols & yermosols lithosols regosols (eutric & dystric)	high slight high	slight average slight-average	sheet erosion in gullies depends on texture
Vertisols -topomorphic -lithomorphic	vertisols -chromusterts pelusterts	vertisols -chromic -pellic	slight	slight-average depending on the quality & size of structure	gully erosion
Calcomagnesimorphic soils -(calcareous browns)	inceptisols (xerochrepts)	cambisol (calcic)	slight	high	not very scattered soils
Isohumic soils -subarid browns -red-browns -pseudogley browns	aridisols camborthids haplargids	xerosols haplic	average-high slight	slight-average average-high	sheet erosion frequent gullying
Tropical ferruginous soils -unleached -leached to concretions	torripsamments alfisols (haplustalfs, paleustalfs, rhodustalfs)	arenosols luvisols (ferric (glazic	slight slight	slight-average average-high sheet erosion	sensitivity depends on destruction of the surface crust
Halomorphic soils -solonets solodises	natrargids natrargids	solonets	slight	average	frequent gullying

rain available for the soil only represented a fraction of the total rain, the soils actually having a drier pedoclimate than the meteorologic data had indicated in themselves. Note that surface impermeability has another consequence; it blocks the capillary and limits losses through evaporation (mulching effect), which is sometimes an advantage.

The tendency toward surface crusting also affects the halomorphic soils developed on granite calcic-alkaline rocks (solidized solonetz). These soils are of little use in agriculture but they are distributed on long glacis which undergo intense runoff in the beginning of the rainy season and, lower down, gullies can occur in places and even tunnel erosion (piping). Soil erodibility, then, cannot be disassociated from the topographic position of the profiles. But Sahel reliefs vary. The principal types are:

- active dunes and flat-topped hills.
- long glacis with slight slopes, either from erosion or accumulation.
- interdunal plains, more or less covered with sand.
- uneroded, indurated hills and reliefs with outcrops.
- valleys and depressions liable to flooding.

The dunes seem to be the most sensitive to alteration but it is impossible to determine the role of current processes. The present dunal forms in the Sahel are the result of at least three arid climatic episodes in the quaternary age (Leprun, 1971). The soils have different morphological characteristics in each of these dunal systems. The oldest have structural and even textural B horizons. The extent of the alterations becomes apparent when the transition between the upper horizons and the generally reddened structural B horizons is examined. One finds that on most of the slopes and the lower part of the dunes these transitions are the result of the B's having been scraped by erosion then covered by moving sands. With degradation by overgrazing (which is not the only case of superficial alteration) it is this sandy upper horizon which moves on, appearing in places on the surface of the B horizons. It is probably wind erosion which was the active factor in this phenomenon, which is often marked by barren strips, the shrubby steppe having been eliminated here.

The number of modern pottery fragments that can be found in the profiles between 40 and 70 cm. shows that numerous alterations date from the most recent centuries of human occupation. The instances of dunal movement around semi-permanent ponds confirm the instability of this Sahelian environment. Gullies have even been found in the lower part of the dunes. These are probably related to the slightly more clayey soil texture found there. On the other hand, it must be pointed out that these are also the dunal fields which show the most rapid regrowth of vegetation.

The glacis are made up of cycles of quaternary erosion and they are the current sites of substantial runoff and, therefore sheet erosion also, but this is hard to evaluate quantitatively. Recent rills are to be found on the accumulation glacis.

All these observations, both those on the soil's morphologic characteristics and those on geomorphology, show the importance of the risk of erosion in the Sahel. But they do not help in the separation of the ancient processes from the current ones, or in determining the intensity of these current processes. The importance of the paleoclimatic histories though indicates that the Sahel soil cover is partially out of balance in relation to current climatic conditions. This unbalance explains the instability of the ecosystems and is one of the reasons erosion is as serious a problem as it is.

QUANTITATIVE EVALUATION OF ERODIBILITY

The morphologic study of the soil profiles, even when complemented by analytic determination does not give any way of quantifying erodibility. Attempts to link erosion and the soil's structural stability in the Central African Republic (Quantin and Combeau, 1962) should be brought to mind though.

Two kinds of quantitative evaluations have been done in Africa, the in situ measurement of runoff and water erosion, and theoretic evaluation using preestablished formulae. All the measurements done in the field up until now involve water erosion. Quantification of wind erosion has only just been undertaken within the framework of an experiment being set up in Niger, complementing certain recent observations (Mainguet and Callot, Guy, 1974; Chamard and Courel, 1975).

1) Experiments with runoff plots.

The results obtained up until now relate to Upper Volta and Niger. For comparison, those obtained in Sé[illegible] Senegal (Table 2) can be included -- that is in a Sudanian zone -- but with a single rainy season like in the Sahel. Those obtained in the Ivory Coast (two rainy seasons are presented in Table 3. In Upper Volta the experiments done at Saria are at the southern limit of the Sahelo-Sudanian zone (850 mm. rainfall) The measurements were done on the various sized plots (200-5,000 m^2) on slight slopes (.8%) characteristic of the relief of the Mossi plateau (Roose, 1972). They had been preceded by preliminary studies (Christol, 1966). The runoff rates are slight in the natural milieu, that is in very open wooded savanna. They vary between 2 and 32% depending on the type of cultivation (Roose, 1972), -- bare soil (control) undergoing

Table 2. Summary of the Annual Results Obtained on Erosion Field Plots in SEFA (1960-62) (Roose, 1967)

No. Plots		1	2	3	4	5	6	7	8
1960	Crops	peanut	peanut	peanut/sorghum	peanut	peanut	rice	peanut	peanut
	Mode	tradit.	dech.	dech/E.V. S.C.	dech.	dech.	dech.	dech.	tradit.
	P	1171	-	1302	-	-	-	-	-
	R mm	220,3	430,5	227,6	328,3	376,5	398,1	375,5	352,4
	R %	18,8	36,8	17,5	25,2	28,9	30,6	28,8	27,1
	E t/ha	5,35	12,15	4,52	3,59	6,99	7,38	6,98	7,30
	Rt kg/ha	1900	2850	2580	2660	2640	400	2120	2580
1961	Crops	rice	rice	rice/peanut	rice	rice	peanut	Sorg/E.V.	fallow
	Mode	tradit.	dech.	S.C. dech.	dech.	dech.	dech.	dech.	tradit.
	P	1231	-	1185	-	-	-	-	-
	R mm	461,1	617,4	374,3	446,6	431,0	470,0	414,4	157,3
	R %	37,5	50,2	31,6	37,7	36,4	39,7	35,0	13,3
	E t/ha	29,95	54,48	8,05	6,79	10,84	5,24	8,65	9,78
	Rt kg/ha	neant	neant	534/1940	1184	872	1720	46.000	-
1962	Crops	peanut	cotton	sorg/grain	sorg/E.V.	peanut	cotton	fallow	fallow
	Mode	tradit.	dech.	dech.	dech.	dech.	dech.	dech.	tradit.
	P	1084	-	1223	-	-	-	-	-
	R mm	247,3	462,8	513,9	296,2	474,3	402,9	130,9	228,3
	R %	22,8	42,7	42,0	24,2	38,8	32,9	14,8	18,7
	E t/ha	2,91	18,52	3,29	1,19	3,32	4,25	1,46	1,85
	Rt kg/ha	1025	266	760	-	2224	460	-	-

P = rain R = run-off E = erosion Rt = crop yield tradit. = traditional dech. = stubble plowing

Table 3. Erosion and Run off with Various Plant Covers Between Abidjan and Ouagadougou

Erosion Field Plots from 90-5,000 m^2 (Roose, 1972)

Stations	Erosion tons/ha/year			Run-off % of annual rains			
	Slope	Natural environment	Bare soil	Crop	Natural environment	Bare soil	Crop
ADIOPODOUME (1956-1971) (ORSTOM)							
Secondary evergreen forest 2100 mm ; 4 seasons 90-250 m^2 plots Climatic erosiveness R_{UA} = 800-1200 (Roose, 1971)	4,5 %	-	60-90	-	-	42	-
	7 %	0,03	100-170	0,1-90	0,14	38	0,5-20
	22 %	0,2	500-750	-	0,7	32	-
	63 %	1,0	-	-	0,7	-	-
BOUAKE (1960-1970) (IRAT-ORSTOM)							
Dense shrubby savanna 1200 mm : 4 seasons 200-250 m^2 plots Erosiveness R_{UA} = 250-500 (Bertrand, 1967)	4 %	0,05-0,20	18-30	0,1-26	0,3	15-30	0,1-26
OUAGADOUGOU (1967-1971) (CTFT-ORSTOM-IRAT)							
Clear wooded savanna 850 mm : 2 seasons 200-5,000 m^2 plots Climatic erosiveness R_{UA} = 250-450 (CTFT, 1971)	0,8 %	0,05-0,15	10-20	0,6-8	2,5	40-60	2 -32

40-60% runoff. Taking into consideration the unbalance between the water contributions and the losses through evapotranspiration, one becomes aware of the seriousness of such superficial losses in time. These losses, though, still may have a role in the agro-pastoral economy because part of the water is caught in depressions, in ponds especially, which are undeniably important when it comes to the survival of herds in the dry season. Erosion (i.e., the amount of soil carried off) likewise varies according to the soil treatments. It can be slight under cultivation but can reach 8 tons, while soil losses from bare soil range from 10-20 tons/ha/year equalling 1000-2000 tons/km^2/year.

In Niger experimentation was done in the Allakoto experimental station (Maggia Valley - Delwaulle, 1973). Annual average rainfall is around 450 mm, the length of the rainy season not exceeding 4 months. The vegetation is a shrubby savanna greatly affected by man and is currently very sparsely cultivated. It is a plateau cut through with large valleys, on which very diverse soils have developed in connection with the great diversity of geologic rocks. Most of these soils are chemically rich, which is exceptional with respect to the largest part of the Sahel and this is why numerous development programs have been set up there. But the seriousness of the erosion phenomena has already caused serious concern among specialists who have sought not only to quantify the phenomenon but also to seek uncomplicated ways of combatting it which are adapted to the socio-economic conditions of the country.

Four plots have been set up. They are on the order of 4000 m^2 — that is, they are comparable to the fields of the Haoussa. They received the following treatments:

Plot 1: isohypse stone walls and plowing

Plot 2: control, traditionally cultivated

Plot 3: contour vegetation rows and plowing

Plot 4: grassy isohypse stone mounds

The area slopes are 2-5% and the soils come from calcareous rocks. The field plots were planted on 3% slopes and on brown calcareous soils (French classification) which correspond well to the calcicxerosols (FAO) and the camborchids (Soil Taxonomy). The study of the distribution during the time of the rainfall showed that there were maximum intensities each year (during a 5 minute period) greater than 74 mm/h. The annual frequency of these intensities varied from 1 to 14 from 1966-1971.

Runoff only occurred after a certain amount of rain had fallen; this was about 12 mm for the control plot. This value is very theoretical though, and the initiation of runoff not only depends on the rain's intensity, but also on the moisture of the upper horizon. It

also varies depending on whether it is the beginning of the rainy season when the soil is bare, or at the end of the rainy season when there is substantial plant cover. Table 4 gives the average percentages of runoff recorded. A noticeable difference is found between the treatments and the annual average runoff is around 20% during the "normal" years. The simple anti-erosion treatments used here are very effective; the runoff is always less than 9%. The values for erosion, that is for soil carried off by runoff, do not agree with the values for runoff. For 1968, which was a year with slight average rainfall, interesting results were obtained. For the traditionally worked field, erosion was greater than 5 tons per hectare, basically caused by two rains. On the other hand erosion on treated plots remained slight and was always less than 500 kg/ha, erosion less than 7.5 tons/hectare being considered tolerable. This problem of the effectiveness of erosion control methods will be taken up again later on.

Other experiments with runoff plots have been done in the Sudanian regions. Although there is cause for reservation, the results, particularly those at Séfa (Senegal), can be considered indicative of the most southern Sahelian or Sudano-Sahelian regions (Fauck, 1954; Fauck, 1956; Roose, 1967). Other results have been obtained with hydraulic catchment basins but they only relate to the computed runoff rates (Brunet-Moret, 1963; Dubief, 1953; Girard, 1975). These studies show the importance of exceptional flooding in maximum flow and volume. These are floodings whose decrease in outflow is hampered from upstream to downstream in hydrographic networks whose morphology is the product of more humid quaternary climates (Rodier, 1975). These results show the existence of periods of very high rates of runoff for well-drained soils. These are mainly at the beginning of the rainy season. In these conditions the annual average runoff value supplied most often in hydrology does not have any great significance for erosion because, for erosion, it is the particularly wet or dry years which are the most important.

2) Experiments with the rain simulator.

Experiments were done in 1976 near Lake Bam in the Voltaic Sahel. The results are still very high during the first rains which fall on dry soil. They fluctuate, in most cases, between 40 and 50 mm/h for 60 mm/h simulated rains (Collinot, 1977, unpublished). Erosion varies considerably depending on the soil. Identical experiment plans (intensity, length of the rains, same initial state of the plots, similar slopes) have given the following extreme values: soils with surface gravel (natural mulch) 0.02 t/ha/hr; thick sandy soil: 1.7 to 2.9 t/ha/hr.

Table 4. Allokoto, average runoff percentages recorded.

Year	Rainfall	R	P1	P2	P3	P4
1966	487.0	180.4	5.1	18	6.1	*
1967	515.3	305.8	5.9	22.5	5.0	0
1968	354.3	150.8	0.8	8.5	1.2	0.6
1969	506.8	178.0	2.3	21.4	6.8	1.2
1970	469.5	250.9	5.6	19.2	8.5	2.1
1971	289.6	152.6	1.3	10.5	1.3	0.3
Moyenne	437.0	198.5	3.8	17.6	5.2	0.9

* Not used

Delwaulle - 1973

Table 5. R value in Upper Volta.

Stations / Year	1966	1967	1968	1969	1970	1971	1972	Average
DORI	440	190	176	491	165	101	262	261
OUAHIGOUYA		390	315	353	225	321	203	301
FADA N'GOURMA	442	526	439	458	302	322	509	428
OUAGADOUGOU		389	252	725	228	414	786	466
SARIA			357	501	389	320	217	357
MOGTEDO			406	457	384	256	378	378
BOBO-DIOULASSO	493	437	664	538	880	421	442	554
FARAKO-BA		365	393	489	736	372	554	485
NIANGOLOKO			707	846	924	314	491	656
GAOUA	419	274	910	644	713	496	310	538

Delwaulle - 1973

3) Theoretic formulae.

The theoretic risk of erosion in the Sahel has been evaluated by different methods. With respect to wind erosion it must be realized that the greatest part of the sandy particles of the dunes are distributed in modes equal to or less than 200 microns and thus are liable to being easily carried off by winds. But real erosion is dependent on the quantity and quality of the aggregates binding these particles. However, examination of current data supplied by wind gauges shows that the average wind velocity is relatively slight (only 15% of the winds have a velocity greater than 5 m/s at Dori (Upper Volta) (Courel, 1977). Evidence of wind processes and the recent evolution of "coudeyrization" (caving in of dunal cavities), though, shows the reality of deflation.

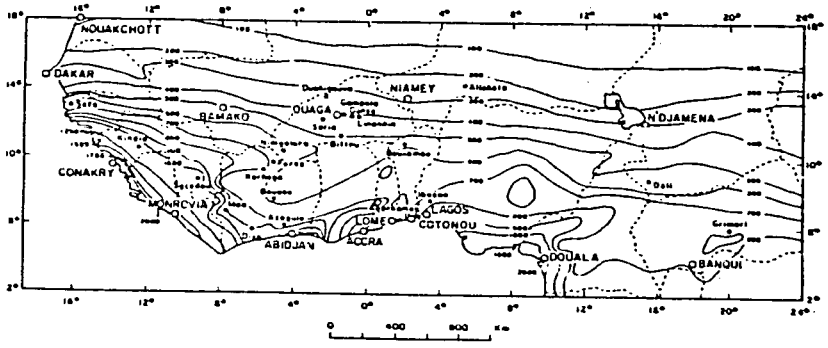
For water erosion it was Fournier (1960 and 1967) who took the first theoretic step using the basic formula p2/P, p being the rainfall in the wettest month and P the normal rainfall. The figures that were obtained vary around 2,000 t per km^2 per year. This is the figure obtained for bare soil in the runoff experiments in Upper Volta. Right now the FAO is trying to use a formula derived from the Fournier formula to characterize small scale erosiveness. But it is the Wischmeie formula that has been most recently used by all the writers. The erosion prediction equation is as follows (Wischmeier and Smith, 1960; Smith and Wischmeier, 1962; Wischmeier and Hannering, 1969; Wischmeier, 1974):

$$A = R.K.C.SL.P.$$

A = average annual soil losses
R = rainfall and associated runoff
K = inherent susceptibility of the soil to erosion by water
C = cover and management
SL = effects of slope length and steepness
P = supplemental practices

R was calculated for all the experiments — that is in those cases where complete meteorologic data were available (Galabert and Millogo, 1973; Roose, 1972). In Ouagedougou the R value in 1968 and 1969 was 480 (Roose and Birot, 1970). But for the other years the values varied from 250-450. In Bambey, Senegal the R value was 292 from 1960-1968, for a region with annual rainfall on the order of 600 mm (Charreau and Nicou, 1971). In Niger Delwaulle computed R values varying from 150 (in 1968) to 250 (in 1970) and 305 (in 1967) (Figure 1). The annual variation is, then, important, and because of this the examination of series of observations over 20-25 years is necessary in the characterization of the climatic aggressivity of a region, as Wischmeier has done for the entire central American plain. In the Sahel region such series of observations are rarely available, but since there are several pluviometric stations with more than 20 years of data an attempt at resolving the problem was

CHART OF THE DISTRIBUTION OF THE INDEX OF CLIMATIC AGGRESSIVENESS ANNUAL AVERAGE (R-USA-WISCHMEIER) IN CENTRAL AND WEST AFRICA SITUATION OF THE EROSION PLOTS



TAKEN FROM PLUVIOMETRIC DATA GATHERED BY THE ORSTOM HYDROLOGIC SERVICE AND STOPPED IN 1975.
ROOSE (1976)

Figure 1.

made by trying to find a connection between R and the amount of rain. West Africa Delwaulle suggested adopting a mean formula for the Sahel zone: R = 0.15884 P 130 - 1.2 (P 130 being the rain's maximum intensity 30 minutes). He computed the R values for certain Sahel stations (Tabl 5). For his part Roose noticed that the ratio between the R index and the raintall always stays around 0.50 except for the mountainous regior He drafted a map of erosiveness using 0.45 for the Ivory Coast savanna with 2 rainy seasons, and 0.55 for the savanna and the Sahelian steppe with one rainy season. With this map (Figure 1), R values in the Sahel can be estimated between 100 and 500. But field observations have led me to use these values only with prudence, taking into account the rair irregularity in time and space in semi-arid regions.

The K factor gives the soil's susceptibility to erosion and it is very important. Various values are currently available... Roose used a simplified method recommended by Wischmeier which used granulometric data, figures for organic matter, structure and permeability. For Uppe Volta the K values computed are between 0.23 and 0.27. These figures are for tropical ferruginous soils which have relatively high amounts of fine sand. The soils, then, are not particularly erosion-prone, something which Charreau had already pointed out for Senegal. Consequently the seriousness of the erosion phenomena is basically due to the aggressiveness of the tropical rains and the lack of plant cover.

There is still insufficient data on the influence of the topographi factor, and before drawing any conclusions and making any generalization the results of current experiments are necessary. The other parameters of the Wischmeier index will be discussed later on.

THE EFFECTS OF EROSION ON PRODUCTION

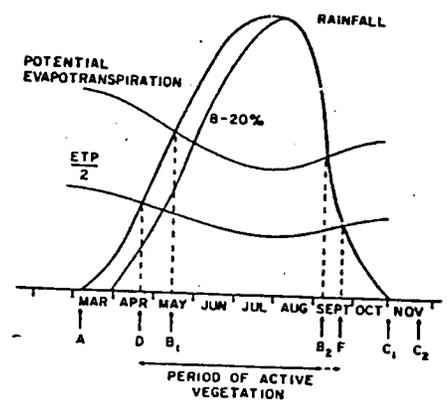
Productivity of pasture land

The problem of pasture land is outside the scope of this study. However, the way dry cultivation and cattle raising complement each othe in the Sahel is important and justifies a brief analysis of the matter. It is currently impossible to give any precise evaluation of the impact of erosion on pasture land. There is a great deal of information on the lack of plant cover in connection with erosion, on the modification of the species involved, on the death of forage trees, on the sanding of certain zones, but the various phenomena of soil degradation and fertility loss are difficult to isolate while the spectacular sanding phenomena have a very localized economic impact. However, experience acquired in the other regions indicates that they should not be underestimated (Lyles, 1975; Chepil et al., 1952). What seems to remain is that all the data acquired on the decrease in primary production are usually related to the decrease in available soil water rather than the intensity of erosion.

The yield of rainfed crops

For traditional rainfed crops like millet, peanut, cowpea (Vcandzou subteranea), cotton, the yields are often very small. But one finds that the two components, runoff and erosion, are equally responsible in lowering fertility. Erosion itself (the carrying off of soil), or its corollary, covering the culluvial deposits or the formation of sandy dunes, represents a usually very localized environmental deterioration, sometimes called desertification. It continues to remain important, even on sandy soils because the peasants prefer to cultivate the dunal slopes. The fertility lost through sheet erosion (the most deceptive) though, or by sand pollution may be underestimated. Besides the impact of salt brought by the wind on the crops is not understood. This salt comes from the saline or alkaline soils of the presahelian regions. Some writers consider this kind of wind pollution important (Borovikii, 1961; Lyles and Schrandt, 1972), but the effects of runoff, independent of element transfer, may be more important in the semi-arid regions. From it results a decrease in infiltration in unflooded soils and an increase in the unbalance between the actual amount of water brought to the soil and the losses through evapotranspiration, thus increasing environmental aridity. The existence of this water deficit does not adequately explain the decrease in yields. Rainfed agriculture in the Sahel regions is determined by the amount of rain as much as by the length of the useful rains (i.e., those determining the length of the plant cycle) (Cocheme and Franquin, 1967). An "intersections" method was suggested by Franquin (1973). With this method three vegetation periods can be defined by comparing the rain distribution curve with the ETP and ETP/2 curve (Figure 2). Actually the comparison of the ETP curves should be established in time, not with the rainfall curve, but with a curve which represents the water that has actually seeped into the soil. One finds that water lost through runoff, around 20% of the total for example (which seems a common enough figure), significantly displaces the curves of the water balance in time in relation to the ETP and ETP/2 curves which remain constant. This results in a decrease not only in potential reserves in the soil but also in the length of the active growth period. This period has a decisive influence on the average yields of the harvests, even if its effect is relatively indirect. It seems possible to me to conclude that the fight to control erosion must be based on controlling runoff by increasing infiltration. The exact effect of erosion on agricultural production has, though, been measured in certain experimental stations in Upper Volta. The cottonseed yield in Upper Volta has been found to be directly related to the intensity of the soil losses, but also to the evolution of water available in the soils and to the percentage of organic matter. Whether it is in traditional cultivation or in improved cultivation (more demanding), it is water which remains the major factor limiting fertility in semi-arid West Africa (Fauck, 1971) -- damage by water erosion and wind erosion adding to the consequences of water lost by runoff.

DETERMINATION OF THE PERIOD OF ACTIVE VEGETATION



O-F (or B) : PERIOD OF ACTIVE VEGETATION

A-C_1 : "RAINY" SEASON

D-C_2 : "HUMID" SEASON

O-B_1 : PRE-HUMID PERIOD

B_1-B_2 : HUMID PERIOD

B_2-C_2 : POST-HUMID PERIOD

THE POSITION OF C_2 DEPENDS ON THE AMOUNT OF WATER STORED IN THE SOIL DURING THE HUMID PERIOD.

P. Franquin (1973)

Figure 2.

CONTROL METHODS

Wind erosion

Methods of control are known (USDA, 1958; Chepil and Woodruff, 1963) and the advantages and disadvantages of the various techniques (Chepil and Moldenhauer, 1962) are data which can be extrapolated in Africa where one must, however, emphasize the importance of sandy materials coming from the wind in relation to the situation found in the United States. The basic idea is to stop or limit the deterioration of the plant cover (by overgrazing especially), which is the basic cause of susceptibility to wind erosion. This is not a simple technical problem, but one with numerous socio-economic and even political overtones (FAO, 1974; United Nations, 1975). Overgrazing mainly results from the concentration of herds around permanent and semi-permanent water sources and its elimination assumes the adoption of a distribution policy for forage and wells which takes into account both the people's customs and the potential for primary production of the different kinds of pasture land in space and also in time. The effectiveness of reserved lands (Depierre and Gillet, 1971) should also be mentioned, but it must be remembered that this involves techniques which are difficult to employ in the Sahel. They show the power of vegetation taking over once again. Ever since normal rainfall has returned after the exceptional dryness in 1968-1973 hard seeds which had stayed in the soil for many years germinated. A considerable plant cover has developed from this in the most arid regions. These areas, temporarily abandoned by human and animal populations, were somewhat naturally preserved. Practically speaking it seems possible to facilitate the regrowth of herbaceous vegetation by harrowing sandy-clayey soils with less than a 10% slope, but the use of this technique is limited due to economic constraints.

Runoff erosion

The choice of control methods is inspired by the results discussed above. Data supplied by various studies on soil use in the semi-arid regions of Africa (Dabin, 1969) on the effects of mechanization on tropical agriculture (Fauck, 1956; Fauck et al., 1969) and those taken from general studies of tropical regions (FAO, 1967; Hudson, 1971) belong here too.

Roose's (1971) determination of the values for the C factors (plant cover and cultivation methods) and P (anti-erosive practices) in the Wischmeier formula must be included. The C factor is the most important conditional factor. It varies as a function of the plant cover. Setting the savanna on fire, for example, especially if it is late, very appreciably increases the runoff and the amount of solid material.

When the soil is completely bare, runoff may be multiplied by 20 with catastrophic soil losses. For cropped soil, C values are very variab Roose's figures (1971), valid for the whole of West Africa, but basic established in the Sudanian or Guinean regions, may be cited.

For bare soil, by definition	C = 1
prairie in good condition	C = 0.01
burned or overgrazed prairie	C = 0.1
sorghum, millet	C = 0.4 - 0.9
cotton	C = 0.5 - 0.7
peanut	C = 0.4 - 0.8

In every case erosion basically depends on the percentage of soil not covered by vegetation at the beginning of the monsoon rains.

The P factor represents classic anti-erosion practices. Roose (1972) and Delwaulle (1973) determined the following values:

tie ridging	P = 0.2 - 0.1
strip cropping	P = 0.3 - 0.1
straw mulching (10 t/ha)	P = 0.01
synthetic mulching	P = 0.5 - 0.2
dry stone ridges, plowing and fertilizer	P = 0.1

These diverse results led the writers to make a limited choice among the various methods of controlling erosion -- building broad based terraces. Experience has shown that terracing techniques are delicate to use in the Sahel socio economic environment and that the terraces made are difficult to maintain. In addition there are scarcel any crops profitable enough to compensate the cost of their constructi Finally, the P factors are less than those found for the United States where P = 0.75 for isohypse plowing. Taking this into account, the wri do not recommend building terraces. Delwaulle, however, demonstrated the importance of simple techniques using isohypse dry stone borders. But this is not always possible.

Soil tillage

Plowing and ridging have reduced erosion in most of the experimen Harrowing, which breaks the superficial crust, improves infiltration, especially for sandy and sandy-clayey soils (Charreau and Nicou, 1971)

On sandy-clayey soils in more humid regions, though, precautions need to be taken practicing surface tillage (Charreau and Fauck, 1970) but if they are taken, plowing distinctly increases the yields of rainfed crops. Delwaulle also found higher erosion during runoff occurring after plowing in Upper Volta. The cultivation method, then, needs to be adapted to the soil type, especially by plowing deeper and by choosing a soil tillage method with minimal plowing under. CIDR at Gorum-Gorum (Upper Volta) used sub-soiling techniques which produced good results, mainly for tree regeneration, and harrowing techniques which accelerated the growth of the plant cover. Among techniques commonly used in other arid regions in the world (USA, Australia) it is the least complex ones and those allowing the best water infiltration that are to be recommended. Also, these practices should be undertaken just before the first rains.

Biologic methods

These use plant action. The plant either protects the soil against the impact of drops of rain (splash) or provides soil cohesion (roots and contributions of organic matter), or mechanically stops runoff. Roose's observations confirm the superiority of biologic methods over mechanical methods (terracing). Whenever it is possible the initiation of vegetation must be facilitated which leads to establishing the importance of early and dense sowing, spreading fertilizer, phytosanitary control and finally the use of improved varieties with a rapid growth rate. Stopping runoff will result in an improvement of the water balance and, correlatively, in better vegetation, better erosion protection, and, finally, higher yields. The use of dead plant cover should also be recommended, for example, if possible, a partial burying of millet and sorghum straw. It should be noted though that cereal stems are often used for domestic purposes (kitchen, fences, roofing) and they are rapidly eaten by cattle or destroyed by termites. These observations lead one to recommend the study of technical solutions adapted to the local socio-economic conditions. In the most Sahelian regions the millet crops are reserved for the dunal sandy soils, pasture land also being soils with shallow glacis or clay. The erosion phenomena do not have the same importance for these two major soil categories and the previously cited technical solutions must be chosen, taking into account the whole natural and human environment as any modification of runoff on the glacis could disturb the balance of the neighboring sectors. This means that Sahel management must be done on the basis of ecological data (UNESCO-MAB, 1974). Practically speaking, we need to develop an integrated agriculture/cattle-raising system stemming from a basic principle, improvement of the seepage of runoff waters into the soils, at least into those which can accept them.

CONCLUSIONS

Our current knowledge of the Sahel soil erosion shows the agressiv ness of the rains, the Wischmeier R coefficient varying from 250-500 which is comparable to the southeastern United States where the "iso-erodents" only exceed 500 in certain areas. Other studies, though, indicate that this coefficient is much higher in Sudanian regions and that it exceeds 1,200 in the lower Ivory Coast. The K coefficient vari from 0.23-0.27 and the soil's susceptibility to erosion is, then, avera This coefficient varies in the United States from 0.03 to 0.60.

There are, however, many gaps in our knowledge. We only have an imperfect understanding of the wind's erosive power and the K values have only been determined for some soil types. Besides the soil water dynamic has only been the object of local or qualitative studies. However, it may be concluded that the principle basic to any anti-erosion management must be the increase of infiltration into the soils. The techniques are known and the simplest are usually the most effective. To apply them, though, we must go beyond the limits of simple erosion problems. An integrated management is needed which takes into account the diversity of the environment resulting from the wide range of soil types and geomorphologic situations. The Sahel represents very diverse ecosystems which have one common dominant factor: aridity, and one fact: unstable balances. It would be dangerous to stop erosion by causing the infiltration of all the runoff waters if that meant the drying up of semi-permanent ponds whose existence determines the pastora life and the nomadism. Besides, any anti-erosion method which does not take into account the local socio-economic context would be doomed to failure. It could even result in a local aggravation of erosion danger, not to mention the effects on health that could come from the dissemination of certain diseases transmitted by water (bilharziose etc.).

In fact, erosion is but one aspect of a many-sided breakdown in balance. All its aspects must be considered. Breakdown in equilibrium may not only be caused by human activity in relation to the population increase but also comes from climatic risks. These risks are unforeseeable and unavoidable and the possibility of the return of periods of exceptional dryness must be recognized. After these periods "normal" rains will cause great erosion damage because of the degraded state of plant cover. Any ecosystem development project must, then, provide for these climatic risks. Use of the Wischmeier erosion prediction equation (determined by the results expected from current studies) can supply the basic data to correctly define these managements within the framework of an integrated development, but the evaluation of the erosion risk is generally based on the average climatic data over 20-25 years. To perfect the management it may be necessary not only to use this "normal" mean, but also the theoretic values computed from data taken during exceptional years.

References Cited

Aubert, G. 1961. Les sols de la zone aride. Etude de leur formation, de leurs caractères, de leur utilisation et de leur conservation. UNESCO.

Audry, P. and C. Rosetti. 1962. Observations sur les sols et la végétation en Mauritanie du sud-est et sur la bordure adjacente du Mali (1959 et 1961). Prospection écologique. Etudes en Afrique occidentale. FAO. Rome. 267 p.

Barbey, C. and J. P. Carbonnel. 1972. Le ravinement dunaire en milieu Sahélien. Observations lors de pluies récentes dans la région de Nouakchott (Mauritanie). Académie des Sciences de Paris CR 274: 2933-2935.

Berry, L. 1974. Le Sahel: climats et sols. Pages 9-18 in Le Sahel: bases écologiques de l'aménagement. Notes techniques du MAB. UNESCO.

Bertrand, R. 1967. L'érosion hydrique. Nature et évolution des matériaux enlevés. Relations et conséquences sur le sol érodé (station de Bouaké, Côte d'Ivoire). Colloque. Fertilité Sols Tropicaux 2(106)1281-1295.

Bille, J. C. 1974. Année sèche au Sahel. La terre et la vie. Revue d'écologie appliquée 28(1):5-20.

Birch, H. F. 1960. Soil drying and soil fertility. Trop Agr. 37(1):3-10.

Borovskii, V. M. 1961. Salt exchange between the sea and the land, and long-term dynamics of soil processes. Soviet Soil Sci 3: 237-244.

Boudet, G. 1972. Désertification de l'Afrique tropicale sèche. Adansonia série 2 12(4):505-524.

Boulet, R., R. Fauck, B. Kaloga, J. C. Leprun, J. Vieillefon and J. Riquier. 1971. Carte pédologique au 1/5 millions de l'Afrique de l'ouest avec notice. Atlas intl. Afrique occidentale. IFAN Dakar-OUA.

Brunet-Moret, Y. 1963. Etude générale des averses exceptionnelles en Afrique occidentale: République de Haute-Volta. Rapport multigr. ORSTOM-CIEH. 23 p.

CTFT. 1973. Contributions à l'étude de la désertification de l'Afric tropicale sèche. Bois Forêts Trop 139, 148-150.

Chamard, P. C. and M. F. Courel. 1975. Contribution à l'étude géomor phologique du Sahel. Les formes dunaires du Niger occidental et de la Haute-Volta septentrionnale. Ass. Sen. Et. Quat. Afr. Bull Liais. 44. Juin.

Charreau, C. and R. Fauck. 1970. Mise au point sur l'utilisation agricole des sols de la région de Sefa. Agron Trop 25(2):151-191

Charreau, C. and R. Nicou. 1971. L'amélioration du profil cultural dans les sols sableux et sablo-argileux de la zone tropicale sèche ouest-africaine et ses incidences agronomiques d'après les travaux des chercheurs de l'IRAT en Afrique de l'Ouest. Multigr. 248 p.

Chepil, W. S., C. L. Englehorn and A. W. Zingg. 1952. The effect of cultivation on erodibility of soils by wind. Soil Sci Soc Amer Proc 16(1):19-21.

Chepil, W. S. and W. C. Moldenhauer. 1962. Deep plowing of sandy soil. USDA Prod Res Rep 64.

Chepil, W. S. and N. P. Woodruff. 1963. The physics of wind erosion and its control. Advance Agron 15:211-302.

Christol, R. 1966. Mesure de l'érosion en Haute-Volta. Oléagineux 21(8-9):531-534.

Cocheme, J. and P. Franquin. 1967. Projet conjoint d'agroclimatologie FAO/UNESCO/OMM. Rapport technique sur une étude d'agroclimatologie de l'Afrique sèche au sud du Sahara en Afrique occidentale. FAO. Rome.

Courel, M. F. 1977. Etude géomorphologique des dunes du Sahel. Niger nord occidentale, Haute-Volta septentrionnale. Roneo provisoire.

Dabin, B. 1969. Etude générale des conditions d'utilisation des sols la cuvette tchadienne. Travaux et documents de l'ORSTOM.

Dabin, B., R. Fauck and J. Pias. 1967. Les sols de l'aire de l'étude. In A study of the agroclimatology of the semi-arid area south of the Sahara in West Africa. FAO. Rome. 21 p.

Delwaulle, J. C. 1973. Résultats de six années d'observations sur l'érosion au Niger. Bois Forêts Trop 150:15-36.

Depierre, D. and H. Gillet. 1971. Désertification de la zone sahélien au Tchad (bilan de dix années de mise en defens). Bois Forêts Tro 139:3-26.

Dregne, H. E. 1976. Soils of arid regions: developments in soil science. Elsevier Sci Publ Co. 237 p.

Dubief, J. 1953. Essai sur l'hydrologie superficielle au Sahara. Gouvernement Général Algérie. 457 p.

FAO. 1967. Le défense des terres cultivées contre l'érosion hydrique. Coll. FAO Progrès et mise en valeur. Agriculture 81:202.

FAO. 1974. Amélioration de la productivité dans les zones à faible pluviosité. FAO. Roneo.

FAO-UNESCO. 1974. Soil map of the world 1/5.000.000. Vol 5.

Fauck, R. 1954. Les facteurs et les intensités de l'érosion en Moyenne Casamance. 5th Intl Congress Soil Sci 3(4):376-379.

Fauck, R. 1956. Erosion et mécanisation agricole. Publ Bureau des sols AOF. 24 p.

Fauck, R. 1956. Evolution des sols sous culture mécanisée dans les régions tropicales. 6th Intl Congress Soil Sci, vol E:593-596.

Fauck, R. 1967. Traces d'influence paléoclimatique dans les sols d'Afrique occidentale. Bull IFAN 28(1)381-384. (Série A)

Fauck, R. 1971. Les sols des régions semi-arides au sud du Sahara et leur propriétés physiques: réserves d'eau du sol, écoulement et érosion. Pages 61-67 in Agroclimatology in the semi-arid areas south of the Sahara. FAO/UNESCO/WHO 340.

Fauck, R., C. Moureaux and C. Thomann. 1969. Bilans de l'évolution des sols de Sefa (Casamance, Sénégal) après quinze années de culture continue. Agron Trop 24(3):263-301.

Fournier, F. 1950. Climat et érosion. Presse Universitaire de France. Paris. 201 p.

Fournier, F. 1967. Le recherche en érosion et conservation des sols dans le continent africain. Sols Africains 12(1):5-51.

Franquin, P. 1973. Analyse agroclimatique en régions tropicales: méthode des intersections en période fréquentielle de végétation. Agron Trop 28:665-682.

Galzbert, J. and E. Millogo. 1973. Equation universelle de pertes de sols Wischmeier. Le facteur R en Haute-Volta. Agressivité du climat du aux précipitations indice d'érosion par la pluie.

Gavaud, M. 1968. Les sols bien drainés sur matériaux sableux du Niger. Essai de systématique régionale. Cah ORSTOM série pédol 7(3-4): 277-307.

Girard, G. 1975. Les modèles hydrologiques pour l'évaluation des lames écoulées en zone sahélienne et leurs contraintes. Cah ORSTOM série hydrol 12(3):189-221.

Hudson, N. W. 1971. Soil conservation. B. T. Batsford. London. 320 p

LeHouerou, H. N. 1973. Contribution à une bibliographie des phénomènes de désertification, de l'écologie végétale, des pâturages et du nomadisme dans les régions arides de l'Afrique et de l'Asie du sud-ouest. FAO. Soil 1973. 884 p. Multigr.

Leprun, J. C. 1971. Nouvelles observations sur les formations dunaires sableuses fixées au Ferlo nord occidental (Sénégal). Ouest Africa Bull 31:69-78.

Lyles, L. and R. L. Schrandt. 1972. Wind erodibility as influenced by rainfall and soil salinity. Soil Sci 114(5):367-372.

Lyles, L. 1975. Possible effects of wind erosion on soil productivity. J Soil Water Conserv 30(6):279-283.

Mainguet, Callot and Guy. 1974. Les dunes dans l'erg de Fachi-Belma classement taxonomique: diagnostic du sens et de la direction au vent. Revue photo interprétation.

Monod, T. 1973. Le dégradation du monde vivant: flore et faune: les problèmes de la désertification au sud du Sahara - le cas de la Mauritanie. Colloque de Nouakchott.

Nicou, R. 1974. Synthèse des études de physiques du sol réalisées par l'IRAT en Afrique tropicale sèche. Comm seminaire sur les sols tropicaux Ibadan. 19 p.

Nicou, R. 1974. Le problème de la prise en masse à la déssication des sols sableux et sablo-argileux de la zone tropicale sèche. Agron Trop 4:325-343.

Quantin, P. and A. Combeau. 1962. Relation entre érosion et stabilité structurale du sol. CR Acad Sci. Paris.

Rijks, D. 1971-1972. Données météorologiques recueillies à Richard-Toll, Guède, Kaudi et Same. June 1970 and May 1972. FAO. Saint-Louis.

Riou, C. 1972. Etude de l'évaporation en Afrique centrale. Cah ORSTOM série hydrol 9:39-51.

Rodier, J. A. 1975. Evaluation de l'écoulement annuel dans le Sahel tropical Africain. Travaux et documents de l'ORSTOM 46. 121 p.

Roose, E. S. 1967. Dix années de mesure de l'érosion et du ruissellement au Sénégal. Agron Trop 22(2):123-152.

Roose, E. S. 1971. Influence des modifications du milieu naturel sur l'érosion et le bilan hydrique et chimique suite à la mise en culture sous climat tropical. ORSTOM. Abidjan. 20 p.

Roose, E. S. 1971. Projet de lutte contre l'érosion hydrique sur le plateau Mossi (Haute-Volta). ORSTOM. Adiopodoumé. 22 p.

Roose, E. S. and Y. Birot. 1970. Mesure de l'érosion et du lessivage oblique et vertical sous une savane arbrée du plateau Mossi (Gonse, Haute-Volta). Rapport ORSTOM-CTFT. Roneo.

Roose, E. S. 1972. Quelques effets des pluies sur la mise en valeur des sols ferrallitiques et ferrugineaux tropicaux. ORSTOM. Abidjan. Roneo. 15 p.

Smith, D. D. and W. H. Wischmeier. 1962. Rainfall erosion. Advance Agron 14:109-148.

UNESCO. 1974. Le Sahel: bases écologiques de l'aménagement. MAB. Les Presses de l'UNESCO.

USDA. 1958. Soil conditions that influence wind erosion. Technical Bulletin 1185.

United Nations. 1975. Obstacles au développement des zones arides et semi-arides. Rapport du Groupe Ad hoc Inter-Institutions.

Wischmeier, W. H. and D. D. Smith. 1960. A universal soil loss estimating equation to guide conservation farm planning. 7th Int Cong Soil Sci 1:418-425.

Wischmeier, W. H. and J. V. Mannering. 1969. Relation of soil properties to its erodibility. Soil Sci Soc Amer Proc 33:131-137.

Wischmeier, W. H. 1974. New developments in estimating water erosion. Soil Conserv Soc Amer Proc, 29th Ann Mtg. New York.

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Dunne, T. 1977. Studying patterns of soil erosion in Kenya. FAO Soils Bulletin 33:109-122.

Paper No. 7

STUDYING PATTERNS OF SOIL EROSION IN KENYA

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1. INTRODUCTION

Soil erosion is intense in many areas of developing countries because of erosive climatic conditions, rugged terrain, and heavy land use, yet little quantitative information is available about the patterns of erosion. This ignorance limits an assessment of the real magnitude of erosion problems, or the ranking of priority regions for the most urgent soil conservation programmes. When sites are chosen for reservoir impoundment or other water resource development, a rapid assessment of sediment transport is usually made but very few such studies are continued for a long enough period to sample the vagaries of weather and flow which characterize the hydrologic regimes of most developing countries. The accumulation of information on soil erosion and sediment yields is usually too meagre and too late for adequate design (Dunne and Ongweny, 1976).

The situation requires the training and support of a small number of field scientists in developing nations who will be concerned with field assessment of erosion and sediment transport. They should be able to take advantage of hydrologic records which have sometimes been accumulated for years and have lain unanalyzed in the files of water-resource agencies. Such scientists should also be capable of setting up networks of stations for the collection of data on erosion and sedimentation in hitherto ungauged areas, and of carrying out field experiments on soil erosion. The cost of such work would not be high, relative to its value, but the success of the work requires a commitment to field work and continuity of purpose which is frequently lacking.

In this paper, I review some work on patterns of soil erosion in Kenya and refer to relatively inexpensive methods of studying erosion processes and patterns. It will also indicate some of the gaps in our knowledge of soil erosion, particularly in developing countries where physical and land use conditions differ from the more intensively studied, commercial agricultural region of developed countries.

It is appropriate to stress from the outset, however, that the accumulation of field measurements is not enough. In developed countries, large amounts of money have been spent on monitoring programmes and the data have lain unanalyzed for long periods of time. Developing countries cannot afford this waste, and the field scientist must be encouraged to analyze data as they accumulate. This part of the scientific training is as important as instruction in field methods.

Methods of Quantifying Erosion Rates

There are two basic approaches to the study of erosion patterns. The first involves sampling the rate of sediment transport past some point on a river channel at the outlet of a drainage basin. This method is relatively cheap, and it is easy to monitor soil loss rates from large, representative areas by installing gauging stations on a few rivers. Because the measurement of sediment loss is made at a single point, however, it is not possible to interpret much about the spatial pattern

of erosion within the catchment. Nevertheless, sediment monitoring is the most widely used method of assessing soil erosion rates and many water-resource agencies collect suspended sediment records routinely. It is useful, therefore, to consider methods of extracting the maximum possible information from such records.

The second method of quantifying soil erosion involves direct measurement of soil removal by individual processes at a number of sampling sites within the drainage basin. By strategic location of plots, erosion pins, surveyed cross-sections of gullies and river channels, it is possible to define the spatial pattern of soil loss, and to study the local controls of erosion. If measurement sites are distributed so as to sample a range of hillslope gradient, soil types, land use, and conservation practices, for example, the effects of these variables on soil erosion can be isolated and quantified. This kind of information is necessary in the design of land-use and conservation strategies for developing countries. Yet very few measurements of hillslope erosion processes are presently being made in these lands. There is a need to encourage scientists in these countries to use the techniques that are now available. The most useful field methods are described in another paper (Dunne, 1976 a), which includes a bibliography of original sources.

Both of the approaches referred to above include systematic monitoring. The concept of environmental monitoring is gaining acceptance and support (U.N. Conference on the Human Environment, Stockholm, 1972) and we can reasonably look forward to an increase of erosion measurements in developing countries in the near future. In order to interpret the results from monitoring networks, however, it is usually necessary to carry out some controlled experiments of erosion under different conditions of hillslope gradient, land use, conservation practice or other variables of interest. The most common type of controlled experiment involves measuring soil loss from small hillside plots under natural or artificial rainfall (Sattawar and Rao, 1969; Dunne, 1976b; Fournier, 1967; Goel et al, 1968; Hudson, 1971; Vasudevaiah et al, 1965). The plots can be subjected to various treatments, such as removal of vegetation, trampling, or the growing of various crops. They are useful for previewing the soil erosion consequences of a range of management options.

Each of these approaches is presently being used to study the pattern of soil erosion in Kenya.

2. SEDIMENT YIELDS OF KENYAN RIVERS

During the period 1962-68, suspended sediment concentrations were measured by the depth-integrating method at a large number of river gauging stations throughout south and central Kenya (the only regions of the country which support perennial streams). At 63 stations, the data were adequate for constructing sediment rating curves. Daily discharge records from the same stations were then used in conjunction with the sediment rating curves to calculate suspended sediment yields for drainage basins covering a wide range of climate, topography, and land use. A map of mean annual suspended sediment yields was constructed from the data (Dunne, ms in preparation). Sediment yields range from 8 to 19 570 t/km²/year. The results of this national survey can be used directly for estimating potential rates of sedimentation of proposed reservoir sites. They can also be used for an analysis of the major controls of basin sediment yields.

A great deal of attention has been directed toward quantifying general relationships between basin sediment yield and climate (Langbein and Schumm, 1958; Fournier, 1960; Douglas, 1967; Wilson, 1971). The climatic parameter generally used is mean annual rainfall, either obtained from direct measurements or calculated from mean annual runoff and air temperature. Each of the publications listed above proposes a different relationship between sediment yield and climate. Wilson, who analyzed the most comprehensive set of data, concluded that differences in climatic regime and land use make it impossible to define a single rule relating sediment yield to rainfall or runoff.

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The Kenyan data confirm the suggestion of Wilson, and of Douglas (1967) that land use is the dominant variable which confounds the establishment of general relations of sediment yield and climate. In Kenya, as in many other countries, land use depends partly upon climate but there are important differences of land use in each climatic zone.

In Figure 1, mean annual sediment yield per unit area of catchment is plotted against mean annual runoff. The dominant land use in each catchment is indicated by a symbol. In the absence of a detailed quantitative analysis of land use, the classification was confined to four classes: completely forested; forest covering more than 50 percent of the basin; agriculture covering more than 50 percent of the basin and the remainder under forest, and grazing covering more than 50 percent of the basin. A fifth class, lightly grazed scrub forest, contained only two basins. Even with such a coarse classification of land use, however, a pattern is evident.

The lines in Figure 1 are approximate envelopes for each set of land use symbols, and very few points fall outside the appropriate region of the graph. The envelopes do not separate the symbols completely because of differences in the ruggedness of topography, the degree to which the major land use dominates a basin, the duration of records, and the quality of the original data.

There are dramatic differences of sediment yield between land use types. For a fixed value of runoff in the figure, differences in sediment yields between land use types can vary over two orders of magnitude or more. The graph shows, however, that land use is not the only important variable. Agricultural catchments with heavy runoff may have sediment yields which are far greater than the driest grazing lands.

For each land use type, there is a general increase of sediment yields with annual runoff. The higher runoff yields are associated with heavier rainfalls and therefore with greater kinetic energy for hillslope erosion and stream transport of eroded sediment. Regression analysis for basins in each land use category yielded the following equations, all of which are significant at the 0.05 level:

Forest	Sed. yield = 2.67 $\text{Runoff}^{0.38}$	r = 0.98, n = 4
Forest > Agriculture	Sed. yield = 0.042 $\text{Runoff}^{1.18}$	r = 0.75, n = 10
Agriculture > Forest	Sed. yield = 0.039 $\text{Runoff}^{1.41}$	r = 0.71, n = 39
Grazing dominant	Sed. yield = 0.002 $\text{Runoff}^{2.74}$	r = 0.87, n = 7

The regressions are plotted in Figure 2.

Although only four forested basins were available for this analysis, the results are almost exactly the same over the range of the data as those from a similar analysis of sediment yields from 27 catchments in eastern Australia made by Douglas (1967). The Australian catchments were "selected to avoid as much human disturbance as possible". His results are shown in Figure 2.

For the other land use types, sediment yields are higher than under the complete forest cover. The exponents in the regression equations above also show that sediment yield increases with runoff less rapidly in regions with a forest cover than in cultivated lands, which in turn are less sensitive than rangelands.

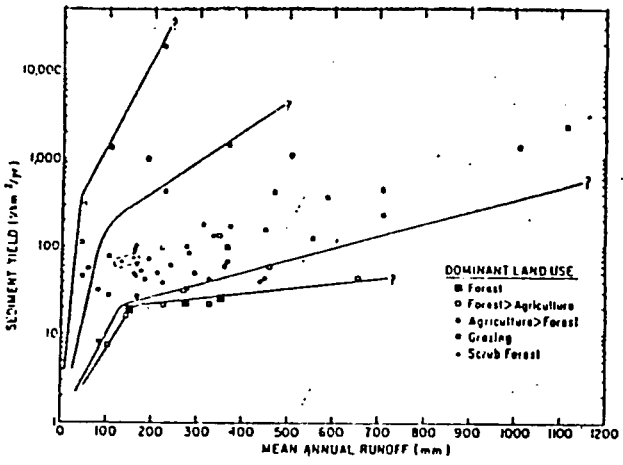

Fig. 1
Mean annual yield of suspended sediment and mean annual runoff for catchments under five dominant types of land use

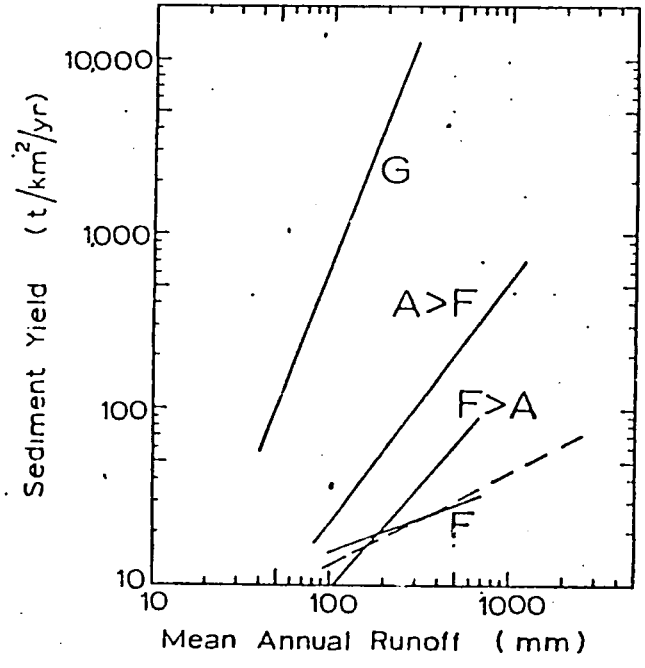

Fig. 2 Comparison of the regression lines computed for the relationship between sediment yield and mean annual runoff for each land use type. The dashed line was computed by Douglas (1967) for forest catchments in eastern Australia

Field observations and visual examination of the data suggested that topographic steepness is a significant factor affecting sediment yields. Measurement of the frequency distribution of hillslope angles in each drainage basin was not feasible with the resources available for this study, and a surrogate measure of basin steepness had to be used. Schumm (1955) showed that the relief ratio of a catchment (its maximum relief divided by the length of the main stream) was positively correlated with sediment loss in Colorado.

The relief ratio was used with mean annual runoff in a stepwise multiple regression of the Kenyan sediment yields. The results were limited because most land use categories contained few points. Runoff proved to be the dominant variable in each case, but only on agricultural lands did relief ratio add significantly to the explanation of the variance in sediment yield. In the other land use classes, however, there was a positive relationship between relief ratio and sediment yield when relief ratio entered the multiple regression as a second variable, and it is likely that the effect of topography would have been demonstrated with a larger sample. The limited data also suggest that in a logarithmic multiple regression equation the exponent of relief ratio increases in the same order as that for runoff. In other words, the effect of basin steepness on sediment yield increases as the vegetation cover becomes sparser. Correction of sediment yields for the effect of catchment area by the method of Brune (1948) did not alter the general form of the results, except by increasing the sediment yields.

No bedload data are available for Kenya and so the yields referred to above underestimate the true soil loss. Field observations suggest that bedload transport is small in the volcanic uplands, where most of the eroded sediment is fine grained. The larger rivers draining the lowlands of Eastern Kenya receive considerable amounts of coarse sand from erosion of soils on schists and gneisses. Some of this material moves as bedload, but its contribution to the basin sediment yield will not be known until a programme of bedload transport measurements is undertaken.

3. HILLSLOPE MEASUREMENTS OF EROSION

In sparsely populated dry regions, where stream flow is rare, there is little likelihood that developing nations can bear the cost of maintaining stream gauging stations for the purpose of assessing sediment yields. Under these conditions, soil erosion can be monitored directly on hillslopes. This can be done by installing plots or networks of erosion pins. Leopold et al, (1966) demonstrated how various techniques for measuring hillslope erosion processes could be used to obtain a sediment budget for a small rangeland catchment. A major problem with all field methods which involve installing even simple equipment, however, is its susceptibility to theft or disturbance.

Soil erosion rates can also be evaluated by measuring recent lowering of the surface against some datable reference. Judson (1958) obtained rates of soil removal from the depth of exposure of Roman archaeological sites. Fence posts often show marks indicating the position of the soil surface at the time of installation. The difference between this height and the present soil surface divided by the age of the fence-line gives the soil erosion rate.

The most widespread indicators of surface lowering in some areas where erosion is intense are exposed tree roots or mounds of residual soil protected under the canopy of trees or bushes while the surrounding soil is lowered (see Fig. 3). If the tree or bush can be aged by counting growth rings (as many tropical species can, in spite of the popular misconception that tropical woody plants do not produce annual or seasonal growth rings), the height of the mound divided by the age of the plant indicates the average rate of surface lowering. In some areas the dating problem is simplified dramatically if there is evidence that soil erosion was accelerated after a period of intensive vegetation clearing. The height of the root exposure or mound can be measured simply and quickly as shown in Figure 4.

Fig. 3 An erosion mound protected by a tree canopy while the surrounding land surface is lowered by erosion. The height of this particular mound is 60 cm

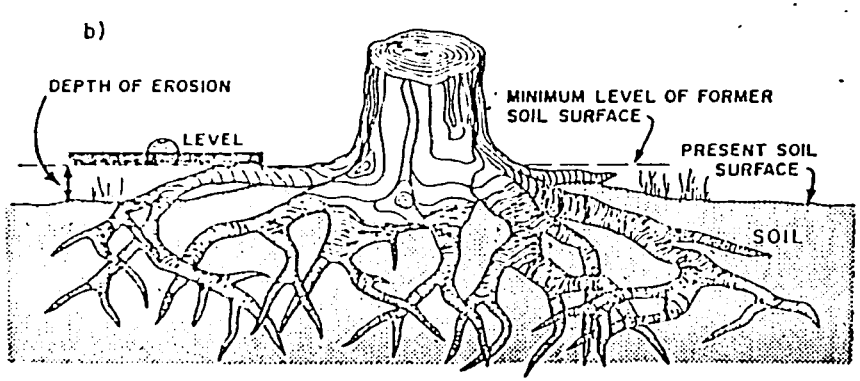

Fig. 4 Measurements of erosion rates from tree root exposures. On suitable tree species the height of the former ground surface is located by examining the tree for signs such as the position of the basal flare or the boundary between trunk bark and root bark. This should be done only after examining trees in relatively uneroded sites. A carpenter's level is then placed at the estimated level of the former land surface and its height above the present soil surface is measured with a ruler

Problems of interpretation arise with this method, and a great deal of care should be taken to check for potential problems in each region before the method is used there. A datable tree species must be found and the tree-ring chronology established, or the onset of accelerated erosion must be dated from aerial photography or other local information. Growth rings can be counted on each tree for which root exposures are measured, but this can be very time-consuming. An alternative method involves cutting down or coring only a sample of trees and constructing a graph of trunk diameter versus age for each species and region (see Figure 5). Each tree used for measuring the erosion rate can then be aged from its stem diameter.

Other sources of uncertainty arise with this method. Some trees produce their own mound by developing a wide basal flare or even by developing buttress roots above the ground surface as they grow. This problem can be avoided by choosing a species which does not have these characteristics. Careful examination of trees in sites which are not undergoing intense erosion (such as plateaux or heavily vegetated areas) should suggest the most useful tree species to use as an erosion indicator in each region. We also compare plants with a range of ages to observe how the plant, its root, and the mound or root exposure develop as the tree or bush grows.

Species, or at least individual trees, which regenerate from old stumps or root stocks should be avoided because the mound is more likely to be related to the age of the older plant than to the new stem. Termites often build mounds around trees and these must also be avoided. Recognition of this problem is not always easy, especially if the mound is no longer colonized and has been eroded. Small termite mounds can usually be recognized by their looser texture and higher organic content than surrounding eroded soils. They also lack pedogenic structures. Mounds produced by wind deposition also have a different structure and texture from the surrounding eroded area, and can be recognized through careful examination. Other sources of uncertainty are described by Eardley (1967) and by Lamarche (1968), who pioneered the method on Bristlecone pines in Utah and in the White Mountains of California.

We incorporate measurements of tree-root exposures into a general hillslope survey of topography, vegetation cover and soils, as described by Leopold and Dunne (1971). At intervals of 100 meters along the hillslope profile we measure the height of the root exposure or erosion mound under the five or ten nearest trees or bushes of the species being used in that area. The procedure illustrated in Figure 4 is carried out on opposite sides of the tree along the contour. The plant is also aged. The average erosion rate for the 5-10 plants is then computed for each site.

The data can be used for mapping the variation of erosion depth along a hillside (Dunne, 1976a, Figure 10) and therefore for computing the total amount of soil lost from a sample of hillslopes in each region. They can also be used for studying the effect of gradient on erosion, as shown for a single rock/soil complex in Figure 6. Measurements of this kind were used to quantify differences in rates of soil loss on three rock/soil complexes in Kajiado District, a heavily grazed rangeland in southern Kenya. I have quantified differences of soil erosion rates on hillslopes with differing gradients, soil types, and intensity of vegetation removal in the Maralal area of northern Kenya. The results are illustrated in Figure 7.

These field measurements show that the rate of soil erosion on even gentle gradients in Kenyan rangelands is extremely high by comparison with the rates compiled by Young (1969) for a variety of regions throughout the world. Over the last 10-20 years, soil has been lost at rates in the range of 0.1 to 0.5 cm/yr on the Athi-Kapiti plain and 0.4 to 1.2 cm/yr in Northern Kenya. These values are equivalent to yields of 1000 - 18 000 t/km^2/yr depending on the bulk density of the soil. It is difficult to compare these values directly with basin sediment yields, because a portion of the soil mobilized from hillsides comes to rest in swales,

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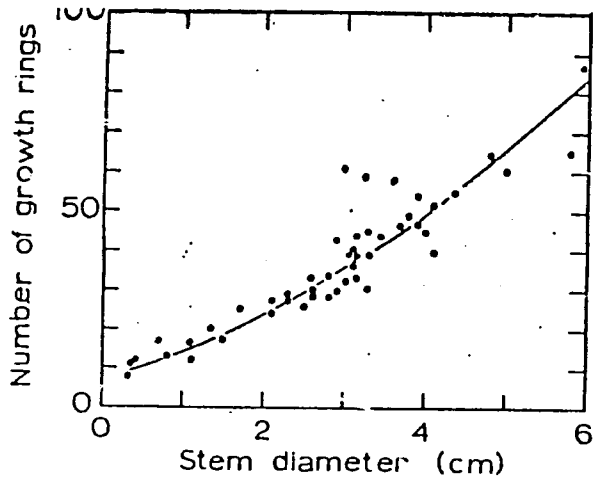

Fig. 5 Relationship between number of seasonal growth rings and trunk diameter 0.25 m above the ground surface for Acacia drepanolobium trees on the Athi-Kapiti plains of Kenya. The rings have not yet been counted under a microscope and so their numbers are still tentative. Biologists measuring plant growth in the region tell us that there are two strong growth periods in each year, even during times of low rainfall

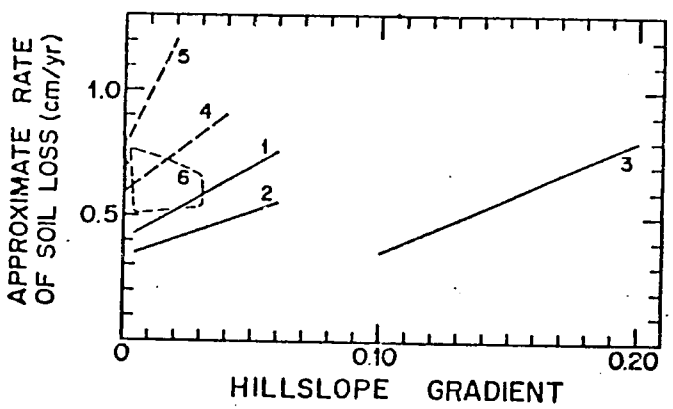

Fig. 7 Average annual rate of soil loss as a function of gradient for hill-sides on two rock types near Baringo and Meralal, N. Kenya. The granitic and gneissic Basement rocks (solid lines) weather to sandier soils than those which develop on the lavas (dashed lines). The former are more resistant than the latter to erosion

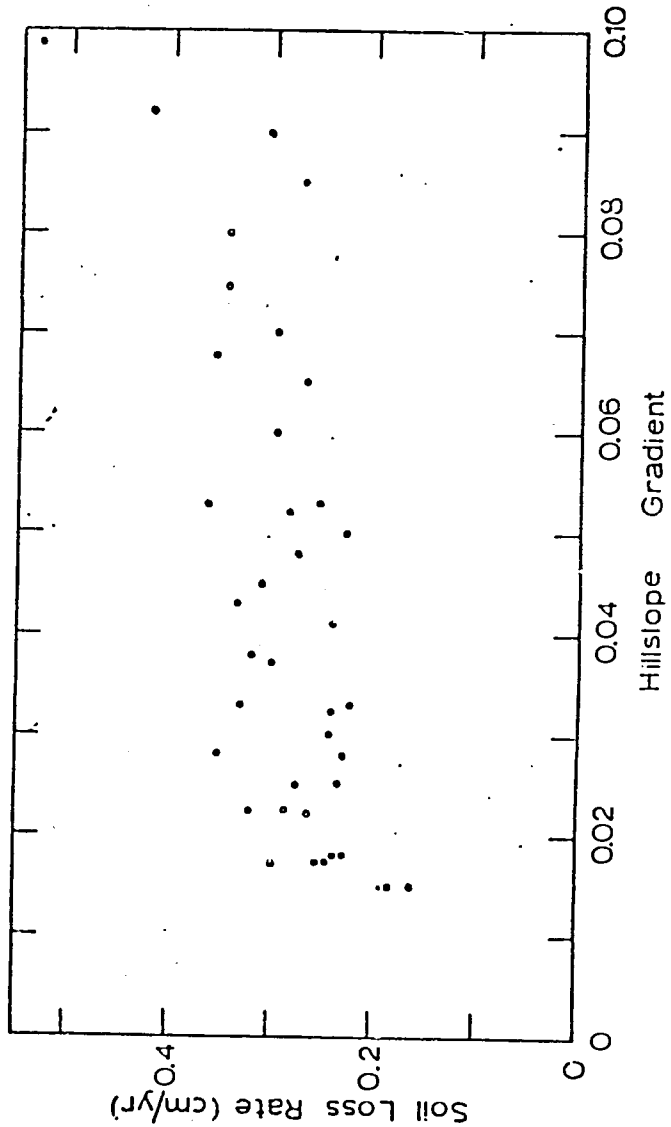

Fig. 6 Average annual rates of soil loss as a function of gradient for 38 sites on 7 grazed hillsides on the Athi-Kapiti plains of Kenya. The rates are tentative until the tree rings from which they were calculated can be checked under a high-powered microscope

floodplains, and other storage sites. The measured sediment yield per unit area for catchments usually declines, therefore, as the size of the basin increases. I know of no published information which indicates the rate at which this decline occurs for arid regions, but in moister agricultural regions of the United States, Brune (1948), Maner(1958), and Roehl (1962) have shown that sediment yield per unit area is proportional to the catchment size raised to a power of approximately - 0.15 to -0.20. Using a value of -0.20 the Kenyan rangeland sediment yields would be approximately 150-2 700 t/km²/yr at 100 km² and of 90-1 620 t/km²/year at 2 000 km². These values are in the same range as most of the basin values for the drier grazing lands in Figure 1, and confirm the evidence that soil erosion there is extreme.

This kind of simple measurement could profitably be made more widely in the rapidly eroding regions of developing countries. Two people with only a hand level, tape, carpenter's level, and rule can make an erosion survey of one to two kilometers per day, and in doing so collect a great deal of information on erosion rates and their controlling factors. In addition to costing little, the method has some other advantages over installing plots to monitor soil loss. The tree-root measurements yield data immediately, rather than the investigator having to wait three or more years to obtain usable data. Secondly the resulting calculations of erosion rate average out inter-annual fluctuations which may distort the picture over a short measurement period on a plot. Thirdly, there are no installations to be disturbed or stolen. On the other hand, monitoring of soil loss from plots or by erosion pins can yield more detailed information, such as the contribution of rainstorms of various sizes. Plots are particularly useful where the rate of erosion is less than the high values shown above, or where trees and bushes are rare. In other words, use of the two methods can be complementary.

In addition to collecting information on soil loss from hillsides we need to know more about the fate of the eroded sediment. There is very little information on this topic even in regions where soil erosion has been studied intensively and almost none for developing countries. Sediment is temporarily stored at many locations as it moves down a drainage basin after its initial release from a hillside. Such locations include footslopes, unchannelled swales, channels and floodplains, lakes and reservoirs. The amount of sediment accumulating at each of these sites is important from both an economic point of view (rates of filling of reservoirs and stock ponds) and an ecological point of view for those interested in the nutrient supply and depth of water holding sediment delivered to swales and floodplains. Our ignorance of the fate of eroded sediment is important to a full understanding of the effects of soil erosion, and could be remedied by a programme of simple, repeated topographic surveys at sites where the sediment accumulates.

CONTROLLED PLOT EXPERIMENTS

To provide quantitative information on the control of soil erosion on Kenyan rangelands, we have begun a set of controlled experiments using a portable sprinkler system which generates artificial rainstorms over a 5m by 2m plot (see Figure 8). With this system a storm of, say, one hour's duration and intensity of 7cm/hr can be applied to plots on a range of hillslope gradients on wet or dry antecedent conditions, with the grass cover in various states. With repeated irrigations of a plot to simulate a whole wet season, we can grow and cut grass to various cover densities.

Both runoff and soil loss rates are monitored during the storm, and a sample of the results from one experiment are given in Figure 9. The results can be used to compare plots on the basis of infiltration capacity, total runoff, or total soil loss. Figure 10, for example, compares soil loss from three soil vegetation complexes in their typical conditions at the end of a dry season. These and similar results will be described in a set of forthcoming papers.

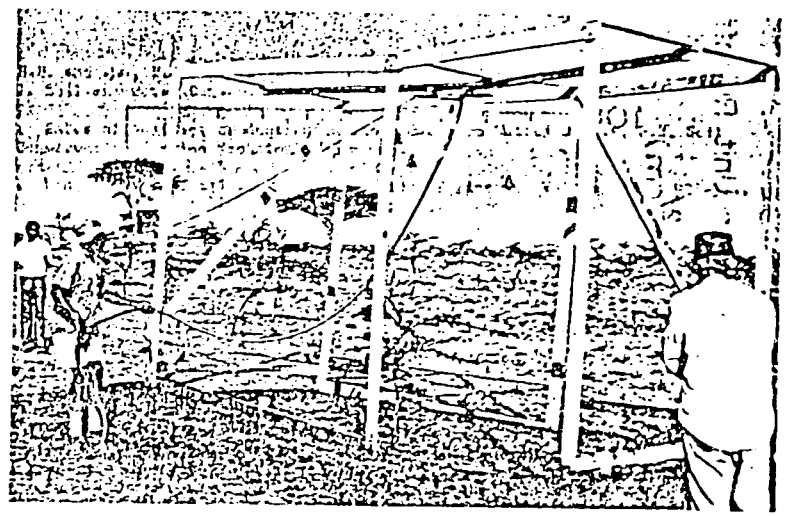

Fig. 8 The sprinkler system used for generating artificial rainstorms on hillside plots in Kajiado District, Kenya

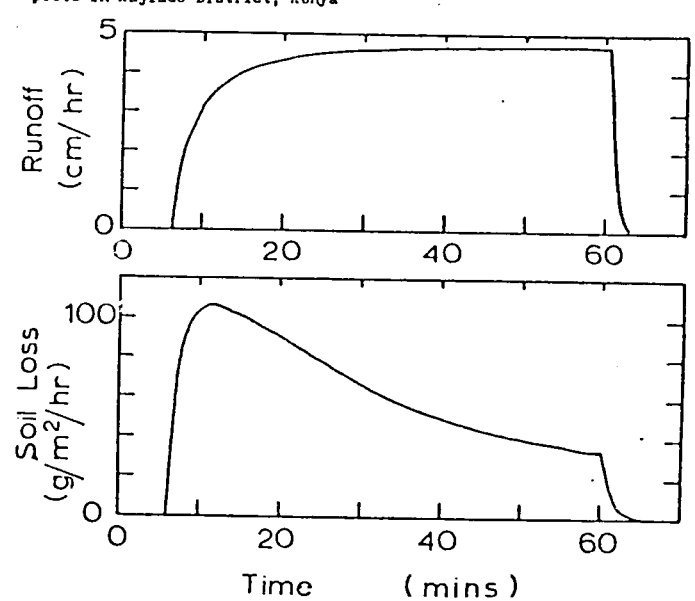

Fig. 9 Hydrographs of runoff and soil loss from a 5m x 2m plot during an artificial rainstorm. Storm duration was one hour and the intensity was 6.9 cm/hr

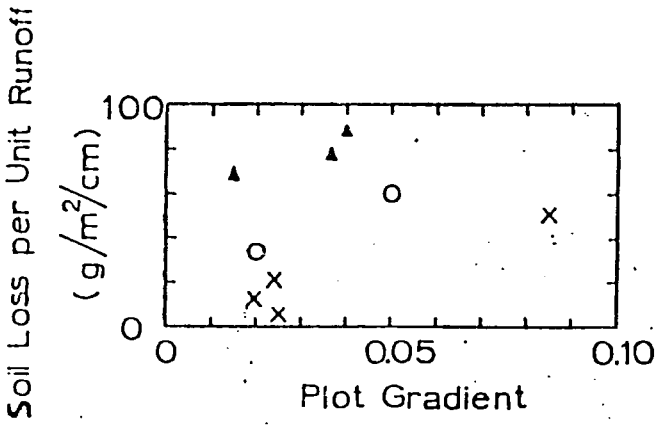

Fig. 10 Total soil loss in a one-hour rainstorm on dry conditions from plots in their usual condition at the end of a dry season. The crosses represent vertisolic clay soils on volcanic rocks with a ground cover averaging 65 - 80%; the circles represent sandy clay loams on schists with a ground cover of about 10%, and the triangles indicate sandy clay loams with covers of 0 - 7% developed on volcanic rocks

SUMMARY

The purpose of the present paper is to indicate the range of approaches available for studying soil erosion in developing countries. Most of the techniques are simple and can be carried out by a small team of field scientists in each country. The cost of such a programme would be small relative to its value, which was reviewed at the beginning of this paper. There are many gaps in our knowledge of the magnitude, distribution, and controls of soil erosion in the tropics. We do not know a great deal about the degree to which various conservation techniques presently reduce soil loss. In view of the present concern about "desertification" and the many pessimistic reviews of the status of eroded lands in some developing countries, it would be worthwhile to collect some quantitative information to form an objective basis for decision making about soil conservation.

ACKNOWLEDGEMENTS

The work reported here was begun with the funding of the McGill-Rockefeller Programme (Prof. T. L. Hills, Director) and the cooperation of the Ministry of Water Development, Nairobi. It was continued with support of the American Philosophical Society and the Explorers' Club. The sprinkling experiments were carried out while the writer was employed as a consultant to the Kenya Wildlife Management Programme (FAO) and the Ministry of Tourism and Wildlife, Government of Kenya.

REFERENCES

Battawar, H.B. and Rao, V.P. Effectiveness of crop-cover for reducing runoff and soil loss.
1969 J. Soil and Water Conservation in India 17(3 and 4): 39-50.

Brune, G.M. Rates of sediment production in the midwestern United States. U.S. Soil
1948 Conservation Service Technical Paper 65.

Douglas, I. Man, vegetation and the sediment yields of rivers. Nature 215: 925-928.
1967

Dunne, T. Evaluation of erosion conditions and trends. In: Watershed management: field
1976a guidelines. S.H. Kunkle (ed.) FAO, Rome (in press).

Dunne, T. Intensity and controls of soil erosion in Kajiado District, Kenya. Consultancy
1976b Report to the Kenya Wildlife Management Project, Nairobi. FAO, Rome.

Dunne, T. and Ongweny, G.S.O. A new estimate of the rate of sedimentation in reservoirs
1976 on the Upper Tana R., Kenya. The Kenyan Geographical Journal, December (in press).

Eardley, A.J. Rates of denudation as measured by bristlecone pines, Cedar Breaks, Utah.
1967 Utah Geological and Mineralogical Survey Special Studies 21, 13 p.

Fournier, F. Climat et érosion: la relation entre l'érosion du sol par l'eau et les
1960 précipitations atmosphériques. Presses Universitaire, Paris, 201 p.

Fournier, F. Research on soil erosion and conservation on the continent of Africa.
1967 African Soils, 12(1): 5-51.

Gool, K.N., Khanna, M.L. and Gupta, R.N. Effect of degree and length of slope and soil
1968 type on plant nutrient losses by water erosion in the alluvial tracts of Uttar Pradesh. J. Soil and Water Conservation in India 16(1 and 2): 1-6.

Hudson, N.H. Soil Conservation. Cornell University Press, Ithaca, N.Y., 320 p.
1971

Judson, S. Erosion rates near Rome, Italy. Science, 160: 1444-1446.
1968

Langbein, W.B. and Schumm, S.A. Yield of sediment in relation to mean annual precipitation.
1958 American Geophysical Union, Transac. 39: 1076-1084.

Leopold, [illegible] and Dunne, T. Field method for hillslope description. Tech. Bull. 7,
1971 [illegible]ish Geomorphological Research Group, 24p.

Meyer, [illegible] Factors affecting sediment delivery ratios in the Red Hills physiographic area.
1958 [illegible]rican Geophysical Union, Transac. 39(4): 669-675.

Roehl, J.W. Sediment source areas, delivery ratios and influencing morphological factors.
1962 International Association of Scientific Hydrology Publication 59, p. 202-213.

Schumm, S.A. The relation of drainage basin relief to sediment loss. International
1955 Association of Scientific Hydrology Publication 36, p. 216-219.

Phillips, R.E., et al. 1980. No-tillage agriculture. Science 208:1108-13

No-Tillage Agriculture

Ronald E. Phillips, Robert L. Blevins, Grant W. Thomas
Wilbur W. Frye, Shirley H. Phillips

For over 100 years, agriculture has relied upon the moldboard plow and disk harrow to prepare soil to produce food. Without the moldboard plow and disk it would not have been possible to control weeds and to obtain the yields necessary to provide favorable economic returns from agriculture. Weeds are strong competitors with food crops for water and plant nutrients, and it was not until plant growth regulators were introduced in the late 1940's that attention was turned to no-tillage agriculture. From plant growth regulators selective herbicides were developed, and these increased the feasibility of growing many different crops without tilling the soil (*1-3*).

In this article, we define conventional tillage as moldboard plowing followed by disking one or more times. By this method one obtains a loose, friable seedbed in the surface 10 centimeters of soil. We define the no-tillage system (*4*) as one in which the crop is planted either entirely without tillage or with just sufficient tillage to allow placement and coverage of the seed with soil to allow it to germinate and emerge. Usually no further cultivation is done before harvesting. Weeds and other competing vegetation are controlled by chemical herbicides. Soil amendments, such as lime and fertilizer, are applied to the soil surface.

In pasture management, chemicals are used as a substitute for tillage, herbicides being used to restrict growth and competition of undesirable plants during the establishment of the newly seeded crop or to supress growth of grasses and allow establishment of legumes. Row crop production with the no-tillage system is almost always carried out by planting the crop into soil covered by a chemically killed grass sod or with dead plant residues of a previous crop. For example, in continuous no-tillage corn (*Zea mays*) production, the soil surface at the time of planting is covered with corn stalk residues of the previous corn crop. In double-cropped soybeans, the soil at the time of planting is covered with residues of a recently harvested small-grain crop such as barley or wheat.

The land area used for row crops and forage crops grown by the no-tillage system has increased rapidly during the past 15 years. In 1974, the U.S. Department of Agriculture (*5*) estimated that the amount of cropland in the United States under no-tillage cultivation was 2.23 million hectares, and that 62 million hectares or 45 percent of the total U.S. cropland (*6*) will be under the no-tillage system by 2000. An estimated 65 percent of the seven major annual crops (corn, soybeans, sorghum, wheat, oats, barley, and rye) will be grown by the no-tillage system by the year 2000 and 78 percent by the year 2010 (*5*). In Kentucky there were 44,000, 160,400, and 220,000 ha of no-tillage corn and soybeans grown in 1969, 1972, and 1978, respectively.

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We estimate that at least 65 percent of the corn and soybeans in the Southern corn belt will be grown with the no-tillage system by the year 2000.

The major advantages of the no-tillage cropping system are as follows. (i) Soil erosion caused by wind and water is reduced. (ii) The acreage of land that can be safely used for row crops is increased because such crops can be grown on sloping land that would be subject to soil erosion by water under the conventional tillage system. (iii) Energy requirements are reduced. (iv) The timing of planting and harvesting can be improved. Row crops on well-drained soils may be planted and harvested under a wider range of soil moisture contents with the no-tillage system than with conventional tillage. (v) Soil water is used more efficiently by plants because of decreased water evaporation from the soil and increased water infiltration into the soil. (vi) The investment in machinery is reduced.

There are several disadvantages in the no-tillage system. (i) The populations of insects and disease-producing organisms and resulting crop damage may be higher than in the conventional tillage system because of a more favorable habitat. The number of rodents may also be increased, but these can be controlled with rodenticides. (ii) Greater management ability is required for success, since there are fewer alternatives for correcting management errors than in conventional tillage systems. (iii) Because a mulch is usually applied to the soil surface in the no-tillage system, soil temperature may be decreased by as much as 6°C at a depth of 2.5 cm in the spring (*7*) or until the plant canopy shades an appreciable proportion of the land area. This lower temperature is a disadvantage when it delays spring planting in areas such as the central and northern United States, or where the soil temperature in the no-tilled soil is below the optimum temperature required for maximum plant growth. In the tropics, however, the lower soil temperature can be advantageous because the soil temperatures are frequently above the optimum required for maximum plant growth.

A reduction in tillage generally requires an increase in the use of pesticides. About 50 percent more pesticides are used for corn production by the no-tillage method than by conventional tillage. Most pesticides used in the no-tillage production of corn and soybeans do not move appreciably in the environment except by soil erosion. Because soil erosion is greatly decreased by no-tillage agriculture in comparison to conventional tillage, one would expect less movement of pesticides from the field. Triplett *et al.* (*8*) found that the transport of herbicides (atrazine and simazine) in runoff water was no greater from no-tilled fields than from conventionally tilled fields. Some pesticides are degraded to harmless components in the soil in a shorter period of time under no-tillage than under conventional tillage (*9*). Thus, although more pesticides are used for the no-tillage system, it appears that the potential for pollution is no greater, and may be less, than for conventional tillage (*8, 9*).

Farmers in many areas of the world are finding that the advantages of the no-tillage system far outweigh the disadvantages. In this time of modern technology it is paradoxical that the no-tillage system combines the use of modern chemicals (selective herbicides) with the most ancient method of introducing seed into soil. Farmers in the mid-Atlantic and the southeastern United States are finding that one or more of the advantages listed above are increasing the net profit of their farming operations as well as conserving their most basic natural resource, soil.

Summary. The no-tillage cropping system, a combination of ancient and modern agricultural practices, has been rapidly increasing in use. By the year 2000, as much as 65 percent of the acreage of crops grown in the United States may be grown by the no-tillage practice. Soil erosion, the major source of pollutants in rural streams, is virtually eliminated when no-tillage agriculture is practiced. The no-tillage system reduces the energy input into corn and soybean production by 7 and 18 percent, respectively, when compared to the conventional tillage system of moldboard plowing followed by disking. In addition, crop yields are as high as or higher than those obtained with traditional tillage practices on large areas of agricultural land.

Soil Erosion

Many studies indicate that no-tillage agriculture reduces soil erosion to almost zero. McGregor *et al.* (*10*) found that on a highly erodible soil in Mississippi erosion was reduced from 17.5 metric tons per hectare to about 1.8 tons per hectare when the no-tillage system was used; Triplett *et al.* (*8*) found that the no-tillage system reduced soil erosion by as much as 50-fold. Harrold and Edwards (*11*) in Ohio compared soil erosion and runoff on watersheds with poor management practices, improved management practices, and no-tillage practices during a severe rainstorm in which 17.5 cm of rain fell in 7 hours. Corn was being grown in all three watersheds. Soil erosion losses for this one rainstorm were 51,477, 7,307, and 72 kilograms of soil per hectare for the watersheds with poor management practices, improved management practices, and no-tillage practices, respectively. The corresponding amounts of runoff were 11.0, 5.8, and 6.2 cm, respectively; and the slopes of the land for the three watersheds were 6.6, 5.8, and 20.7 percent, respectively. Such a severe rainstorm is likely to occur only once in 100 years, however. Harrold *et al.* (*12*) measured soil erosion losses during 5 years of more normal rainfall. Their results from 5 years of continuous no-tillage corn production showed that erosion losses on a 9 percent slope during the growing season decreased from 1761 kg/ha on conventionally tilled watersheds to 27 kg/ha on no-tilled watersheds. In some years, no soil was lost from either conventional or no-tillage systems. However, in 1964, soil loss from the conventional tillage watershed was 6477 kg/ha whereas only 134 kg/ha was lost from the no-tillage watershed. Average corn (grain) yields during the 5-year period were 7091 and 7909 kg/ha for the conventional and no-tillage watersheds, respectively.

Langdale *et al.* (*13*) in Georgia found that on land with a 6 percent slope, the no-tillage system reduced soil loss from about 40 tons to about 0.2 ton per hectare when simulated rain was added at a rate of 6.4 cm/hour for a period of 2 hours. Studies of a tropical soil in Nigeria showed that plots with slopes of 10 to 15 percent lost 7.3 tons of soil per hectare by erosion during a rainstorm of 4.2 cm if they had been plowed and only 0.001 ton if they were under the no-tillage system (*14*). In many regions wind erosion is a problem. A comparison of wind erosion losses by Schmidt and Triplett (*15*) showed that, per hectare, a conventionally planted field of corn lost 291 tons of soil whereas a no-tillage cornfield lost 4.5 tons during one severe windstorm.

In general, soil erosion increases as the amount of tillage increases and decreases as amounts of residues or plant cover increase. By far the most acceptable and effective measure for control of wind and water erosion is the mainte-

nance of surface residues (mulches). Certainly, no-tillage agriculture provides conditions that favor soil conservation.

Water Utilization by Crops

Crop yields from no-tillage agriculture are usually as high as or higher than yields from crops produced by conventional tillage, especially on well to moderately well-drained soils. Except for a few unusual situations, soil water content is almost always higher under the no-tillage system than under conventional tillage (*12, 16–23*). This is mainly because the presence of a mulch on the surface of the soil significantly reduces water evaporation from the soil when the crop canopy does not cover the soil surface. After a full crop canopy is attained, there is little or no difference in soil water evaporation between the conventional tillage and no-tillage methods. For a 4-year period in central Kentucky the average of a Maury silt loam soil at depths of 0 to 15 cm during the corn growing season was 29.5 percent on a volume basis for the no-tillage system and 24.4 percent for conventional tillage. This difference translates into 0.75 cm more water being present in the surface 15 cm of soil under no tillage than in soil under conventional tillage during the growing season. This difference in soil water content can often mean the difference between a good corn yield and a mediocre one. The average amounts of soil water transpired through a corn crop and the amounts of water lost by evaporation to the atmosphere because of tillage during 5 months of four growing seasons in central Kentucky are shown in Table 1. The data show that corn grown by the no-tillage system transpired, on the average, 6.5 cm more water than corn grown by the conventional tillage system. Likewise, soil under the no-tillage system lost 15.0 cm less water to the atmosphere by evaporation than did soil under the conventional tillage system. This improved efficiency of water use is important because food crops are not efficient users of water. Corn, for example, transpires a minimum of 500 kg of water for each kilogram of dry matter produced.

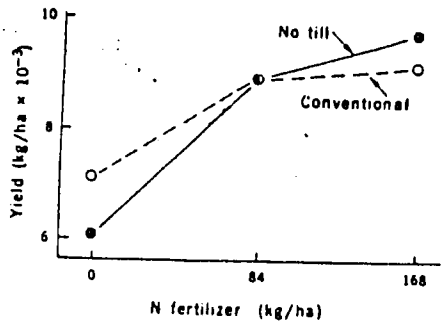

Fig. 1. Response of corn to nitrogen fertilization. The values are the average of eight locations in Kentucky.

Corn Yields

A comparison of corn grain yields from well-drained soils in Kentucky is shown in Table 2. On poorly drained soils, we normally do not obtain as high yields of corn grown by the no-tillage method as we do from conventional tillage. Similar results for well-drained compared to poorly drained soils were obtained in Ohio (*2*). In the northeastern and north central United States, the presence of a mulch consisting of crop residues on the soil surface results in a higher soil water content and lower temperatures in the seed zone at normal planting times. For these reasons, seeding must be delayed to a later than optimum planting date. In addition, nitrate-nitrogen present in the soil may be denitrified and lost from the soil.

Research in Kentucky showed that when nitrogen fertilizer was applied to the soil the corn grain yield on well-drained soils was greater with the no-tillage system than with conventional tillage (see Fig. 1). When no nitrogen fertilizer was applied, corn grain yields were higher with conventional tillage than with the no-tillage system. However, application of 168 kg of nitrogen per hectare resulted in higher yields of corn with the no-tillage system than with conventional tillage; yields were equal when nitrogen was applied at the rate of 84 kg/ha. Results from Maryland were quite similar, as shown in Table 3.

Efficiency of Fertilizer Use in No-Tillage Agriculture

Under the conventional tillage system, fertilizer and lime are mixed with the "plow layer" of the soil, which usually extends from the surface to about 20 cm. Because there is little soil disturbance under the no-tillage system, it is necessary to apply fertilizers to the soil surface instead of mixing them with the soil.

Experiments show that there is little or no difference in potassium availability whether the fertilizer is applied to the soil surface or mixed in. In the case of phosphorus, surface application has a slight advantage over either band placement or mixture of the fertilizer with the soil. There appear to be two reasons for this. First, with the no-tillage system the soil just under the surface mulch remains wetter than any other portion of the soil during much of the growing season. Increased water in the soil improves the diffusion rate of phosphorus to the roots, which proliferate in this zone. Second, application of phosphorus fertilizer to the soil surface effectively achieves the same results as "banding" the phosphorus in the soil. That is, rather limited soil contact with the phosphorus fertilizer results in higher phosphorus solubility. Studies with fertilizers labeled with phosphorus-32 show that more

Table 1. Estimated soil water evaporation and transpiration by corn (*Zea mays*) from no-tilled and conventionally tilled crops on Maury silt loam soil during the growing season. The values, in centimeters, are averages for the growing seasons of 1970, 1971, 1972, and 1973.

Month	No tillage		Conventional tillage		Rainfall
	Transpiration	Evaporation	Transpiration	Evaporation	
May	0.0	2.1	0.0	6.3	17.9
June	7.6	1.0	6.4	6.8	9.7
July	12.4	0.3	9.5	2.1	10.1
August	9.2	0.2	7.2	1.4	4.1
September	1.5	0.5	1.1	2.5	9.1
Total	30.7	4.1	24.2	19.1	50.9

Table 2. Average corn grain yields from well-drained soils under the no-tillage and conventional tillage systems.

Soil type	Number of years tested	Grain yields (kg/ha)	
		No tillage	Conventional tillage
Maury silt loam	8	9,136	8,932
Crider silt loam	5	9,886	8,318
Tilsit silt loam	5	7,705	7,707
Allegheny silt loam	3	10,977	10,909

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Table 3. Efficiency of different increments of nitrogen fertilizer, expressed as kilograms of grain per kilogram of nitrogen, on corn grown on well-drained soils in Kentucky and Maryland.

Nitrogen fertilization per hectare	Yield of corn grain (kilograms per kilogram of nitrogen	
	No tillage	Conventional tillage
	Kentucky	
First 85 kg	35.4	22.2
Second 85 kg	9.6	3.0
	*Maryland**	
First 90 kg	32.4	14.4
Second 45 kg	34.8	3.0
Third 45 kg	0.0	0.0

*See (28).

phosphorus is available to plants when fertilizer is surface-applied.

When nitrogen fertilizer was applied to the soil surface on well-drained soils in Kentucky and Maryland, the amount of corn grain obtained per kilogram of nitrogen was much greater for the no-tillage system than for conventional tillage (see Table 3). However, when no nitrogen fertilizer is applied the yields of corn with the no-tillage system are lower than with conventional tillage (Fig. 1). Some experiments indicate that it is only at the higher rates of nitrogen application that both nitrogen use efficiency and corn yields favor no tillage; this is believed to be because of the higher water content of the soil. However, recent experiments in Kentucky show that when nitrogen fertilization is delayed until 30 days after planting, yields of crops under the no-tillage and conventional system are equal.

In the case of nitrogen fertilizers, there are three possible problems associated with nondisturbance of the soil. The first is that, because of accumulation of organic matter at the soil surface, denitrification can occur when the soil contains an excess of water. This is one of the reasons why no-tillage agriculture is not so successful on poorly drained soils as it is on well-drained land. The second problem is that leaching of nitrate occurs more readily under the no-tillage system both because there is less evaporation of water and because the channels through which water and nitrate can move are undisturbed, promoting deeper penetration into the soil. A third problem is that the native soil nitrogen has a lower mineralization rate in undisturbed compared with disturbed soils. The overall effect of these problems is that more nitrogen may be required for optimum yields of some crops grown under the no-tillage system. In Kentucky, we recommend that, per hectare, 28 kg more nitrogen fertilizer be applied for the production of corn under the no-tillage system than under conventional tillage. Recent experiments in Kentucky show that when nitrogen fertilization was delayed until 30 days after planting, yields of corn at all nitrogen fertilization rates were as great or greater under no tillage than under conventional tillage. In Virginia, 20 percent more nitrogen, phosphorus, and potassium fertilizers are recommended for no-tillage corn to support the 20 percent higher yields expected from this system (24).

Lime placement on the soil surface is effective because under the no-tillage system the soil surface is the zone most

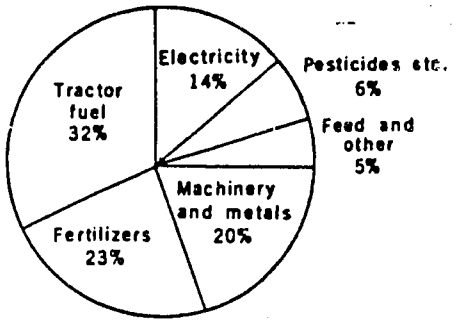

Fig. 2. Energy used in U.S. agriculture. The values given are percentages of total energy used in agriculture. [Courtesy of American Chemical Society (32)]

likely to become acid. This is because of the nitrification that leaves residual acidity at the point of fertilizer placement and the lack of soil mixing that would dilute the effects of such acidity. Thus, lime applied to the soil surface contacts the acidity directly and no mixing is necessary. Work in both Virginia and Kentucky has demonstrated the effectiveness of this method in sustaining crop yields.

Effect of Tillage on Energy Use

The input of pesticides, fertilizers, fuels, and machinery has increased to the point that agriculture is a very energy-dependent industry. The total U.S. energy demand in 1978 was approximately 19.57×10^{15} kilocalories (25). Most estimates place agriculture's share of energy used for the production of food at about 3 percent of the total U.S. energy demand. Of this estimated 0.59×10^{15}

Table 4. Comparison of energy consumption for the product of corn by conventional tillage and the no-tillage system.

Management input or operation	Reference	Energy requirement per unit of input (kcal × 10^3)	Assumption	Energy required per hectare (kcal × 10^3)	
				Conventional tillage	No tillage
Machinery, manufacturing, and repair	(29)	20.5/kg	11.6 kg/ha for conventional tillage; 9.5 kg/ha for no tillage (based on 240-ha farm)	237	195
Fertilizer	(29)				
Nitrogen		13.9/kg (as N)	140 kg/ha	1946	1946
Phosphorus		1.8/kg (as P_2O_5)	70 kg/ha	126	126
Potassium		1.1/kg (as K_2O)	70 kg/ha	77	77
Seed	(30)	4.0/kg	15.9 kg/ha for conventional 18.2 kg/ha for no tillage	64	73
Herbicides and insecticides	(29)	24.2/kg of active ingredients	2.3 kg active ingredient for conventional; 3.4 kg active ingredient for no tillage	56	82
Plow (moldboard)	(30)	235/ha		235	
Disk	(30)	82/ha	One time	82	
Plant	(30)	83/ha	75-cm rows	83	83
Apply herbicides	(31)	17/ha		17	17
Broadcast fertilizer	(30)	18/ha		18	18
Harvest (cornpicker)	(30)	128/ha	75-cm rows	128	128
Dry grain	(29)	0.15/kg	23 to 15 percent moisture (9000 kg/ha yield)	1350	1350
Transport grain	(29)	0.033/kg (3 km distance)	9000 kg/ha yield	297	297
Total				4716	4392

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Table 5. Comparison of energy efficiency of nitrogen fertilizer for the no-tillage and conventional tillage systems of corn production in Kentucky.

Output and input	Energy required per hectare (kcal × 10^3)	
	No tillage	Conventional tillage
First 85 kg of nitrogen fertilizer per hectare		
Yield output*	11,171	5,077
Production input†	1,756	1,457
Gain (+) or loss (−)	+9,415	+3,620
Second 85 kg of nitrogen fertilizer per hectare		
Yield output ‡	4,786	131
Production input†	1,424	1,196
Gain (+) or loss (−)	3,362	−1,065

*3.73 × 10^3 kcal per kilogram of grain. Based on yield increase due to the first 85 kg of nitrogen fertilizer. †Includes energy required to manufacture the nitrogen fertilizer, application of fertilizer to land, and drying and transporting the grain to market. ‡3.73 × 10^3 kcal per kilogram of grain. Based on yield increase due to the second 85 kg of nitrogen fertilizer.

kcal of energy used annually for food production, about one-third is used in the production phase, and two-thirds is used as input manufacturing (Fig. 2). About 80 percent of the energy used by agriculture is from liquid petroleum fuels and natural gas.

Steinhart and Steinhart (26) have described the close connection between farm output and the amount of energy input into the U.S. food system since 1920. Their data indicate, however, that the efficiency ratio for farm output to energy input has declined somewhat in recent years, perhaps emphasizing the need for improved energy efficiency in agriculture.

Conventional tillage requires relatively large amounts of fuel, much of which is used in plowing and disking to prepare a seedbed (Table 4). Since plowing, disking, and some trips over the field with machinery are eliminated with the no-tillage system, a considerable quantity of fuel is saved with this method. However, the requirements for additional herbicides in no-tillage systems offset some of these gains. The elimination of plowing and disking and reduction in machinery manufacture brought about by the no-tillage system results in an annual energy saving equivalent to about 36.6 liters of diesel fuel per hectare. The extra pesticides needed for the no-tillage system offset about 2.65 liters of this saving. Additional seed, which is usually recommended for no-tillage agriculture, offsets another 1 liter per hectare. Thus, the energy saving for the no-tillage production of a hectare of corn is equivalent to about 33 liters of diesel fuel annually compared to conventional tillage. This is about 7 percent less per year for the no-tillage system than for conventional tillage. For soybean production there is about an 18 percent saving of energy in favor of no tillage, 1427 × 10^3 as opposed to 1735 × 10^3 kcal/ha, or about 31.4 liters of diesel fuel equivalent per hectare. Nitrogen fertilizer is not usually used in soybean production since the soybean is a legume. This accounts for the greater percentage saving of energy with no-tillage soybeans compared to no-tillage corn.

The greatest single energy input into corn production is nitrogen fertilizer. In general, 100 to 175 kg of nitrogen fertilizer per hectare are recommended for corn production depending on the type of soil and climatic conditions. In the example shown in Table 4, nitrogen fertilizer represents almost one-half of the energy required. In most soils, nitrogen is the most important fertilizer element for corn production, since it is more likely to be a limiting factor than any other plant nutrient. Table 5 shows that the energy output from increased grain yield for each unit of nitrogen fertilizer applied, when compared to the energy input associated with that unit of nitrogen fertilizer, is much greater for no-tillage agriculture than for conventional tillage. Since the response to nitrogen fertilizer is greater with the no-tillage system (Fig. 1), the energy efficiency values are also greater.

The amount of energy required for various field operations is affected by several factors that are not taken into account in Table 4. Match-up in size between the tractor, equipment, fields, and jobs is an important factor. Size, shape, topography, and type of soil can greatly influence the energy used in field operations. Small or irregularly shaped fields or fields with irregular slopes require more time and energy with respect to equipment use, especially where conventional tillage requires that contour farming be practiced to control soil erosion. The higher the amount of clay in a soil, the higher the quantity of energy required in tillage, especially in those operations involving soil movement such as plowing and disking. These factors favor the no-tillage system over conventional tillage in energy savings, since the no-tillage system requires fewer field operations and practically no soil movement. Less need for use of traditional erosion control practices (contour farming, contour strip-cropping, and terracing) and a much lower loss of plant nutrient supplying capacity in the no-tillage system provide some immediate energy savings. Except for that small amount, the energy savings associated with better erosion control will be largely deferred to future generations. When erosion does occur, large amounts of energy are required to restore the land to productivity (27).

The energy saved by using the no-tillage cropping system may seem small when it is expressed on a per-hectare basis, but it is relatively large when viewed on a national scale. If 65 percent is a reasonable estimate for the percentage of corn and soybeans that will be grown under the no-tillage system by the year 2000 (5), then on the basis of the estimated 35 million hectares each of corn and soybeans by that year, the potential annual savings of energy will be 14.9 × 10^{12} kcal or 1.5 billion liters of diesel fuel equivalent per year for corn and soybeans alone. Although such savings may have little effect on energy use on a national scale, they may be significant for an individual farmer.

Disease and Insect Problems

Some plant diseases, such as take-all in wheat, occur less frequently in no-tillage crops than in crops grown with conventional tillage, and others, such as early anthracnose in corn, occur less frequently in conventionally tilled crops. Some researchers have been concerned about the possibility of no-tillage systems permitting a buildup of a reservoir of disease organisms on crop debris left on the soil surface as mulch. However, there are certain beneficial aspects related to the practice of no-tillage agriculture that should not be overlooked. Conservation of moisture and reduction in soil compaction are factors that contribute to the production of healthier plants that are able to withstand more disease and insect pressures. Thus the fact that corn and sorghum succumb less frequently to stalk rots under reduced tillage systems is not surprising, because

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stalk rots occur more frequently in plants subjected to stress. By avoiding many of the stresses of tillage, plants may be able to withstand greater disease pressures. Regardless of the tillage system used, two practices appear to reduce losses due to disease. First is the use of varieties or hybrids that are resistant to disease, particularly in areas where crops are known to be subject to heavy disease pressures; second, and perhaps more important, is the practice of crop rotation, which benefits disease control in nearly all tillage systems.

Depending on the climate, the presence of mulch and crop residues on the surface of the soil can be advantageous with respect to the control of destructive insects. In areas with large numbers of predators, such as in tropical zones, harmful insects are subject to biological control. In areas where such control is not effective and the mulch serves as a habitat for harmful insect populations, these may be adequately controlled by the soil insecticides used in conventional tillage agriculture in the United States. Systemic insecticides provide adequate protection when they are banded in close proximity to the seed.

Multicropping with No-Tillage Techniques

The potential for multicropping may be the most important factor in no-tillage agriculture. All the advantages of the no-tillage system became more important with multicropping. These advantages include (i) reduced labor and costs; (ii) elimination of moisture loss associated with conventional tillage at planting time, ensuring stands of second and third crops under restricted rainfall patterns; (iii) production of more than one crop per year, which increases land use; (iv) further reduction of soil erosion; (v) maintenance of soil structure by elimination of plowing and land preparation; and (vi) time saved in planting the second and third crops when timeliness of planting is very important.

With the no-tillage system, harvesting can be followed immediately by planting of the succeeding crop, thus reducing the time lag between crops. On well-drained soils, no-tillage crops can be planted over a wider range of soil moisture conditions than can conventional tillage crops, and this further reduces the time before the next crop can be planted in the multicropping sequence. The crops used for multicropping may include seed crops such as small grain, maize, soybeans, grain sorghum, sunflower, flax, and others depending on climatic conditions.

The Worldwide Potential of No-Tillage Crop Production

Factors that will govern the use of the no-tillage system throughout the world include (i) the erodible land that is used for crop production; (ii) soil drainage; (iii) climate; (iv) availability and cost of fuel for agriculture; (v) labor supply; (vi) potential for multicropping, which in turn depends on climate and markets; and (vii) development of technology and management skills to the level needed for the adoption of no-tillage agriculture.

Research data obtained on the use of no-tillage and conventional tillage systems in tropical zones parallel those obtained from research in the southern corn belt with respect to yield increase and reduction of erosion. The fragile soils of the tropics may offer greater opportunity for the long-term advantages of the no-tillage system than any other soils in the world.

Recent studies on the applicability of no-tillage techniques for a range of soils and crops in West Africa have been conducted by the International Institute of Tropical Agriculture in Nigeria. Lal (*19*) reported that corn, soybeans, and cowpeas responded favorably under no-tillage conditions and that soil erosion was adequately controlled. Tropical soils are characterized by thin surface layers and have a high erosion potential because they are exposed to heavy rainfall. Thus the kind and amount of tillage play a vital role in controlling erosion in the tropics. According to Lal (*19*), advantages of the no-tillage system in tropical environments include (i) improved soil structure and soil porosity, (ii) effective erosion control, (iii) conservation of soil moisture in the soil surface, (iv) lowering of the daily maximum soil temperature at the soil surface to a level more favorable for plant growth, (v) maintenance for soil organic matter, and (vi) improved water use efficiency.

Results from South America and the Philippines and other parts of Asia also indicate that the no-tillage system will soon become more widely used in many parts of the world. Although the system has been adopted primarily by farmers practicing agriculture on a large scale, it is likely to find favor on small farms. The energy required to prepare soil for planting with the use of hand tools in most cases limits the total area of food crops that a family can grow. It has been demonstrated in Colombia that by careful application of herbicides by means of a small hand pump, maize can be grown satisfactorally without tillage.

References and Notes

1. S. H. Phillips and H. M. Young, *No-Tillage Farming* (Rieman, Milwaukee, Wis., 1973).
2. G. B. Triplett, Jr., and D. M. Van Doren, *Sci. Am.* **236**, 28 (1977).
3. See *J. Soil Water Conserv.* **32**, 9 (1977); Soil Conservation Society of America, *Proceedings of a National Conference on Conservation Tillage, Ankeny, Iowa* (1973), pp. 1-241.
4. Several other terms, such as zero tillage, minimum tillage, reduced tillage, mulch tillage, direct seeding or drilling, sod planting, stubble planting, and ecological systems, are sometimes used to describe systems similar to what we are defining as no tillage.
5. U.S. Department of Agriculture, Office of Planning and Evaluation, "Minimum tillage: A preliminary technology assessment." Part II of a report for the Committee on Agriculture and Forestry, United States Senate, (Government Printing Office, Publ. No. 57-398, Washington, D.C., 1975).
6. Total cropland includes corn, sorghum, soybeans, wheat, oats, barley, rye, horticultural crops, perennial hay, and pasture and idle or fallow land (*5*).
7. R. E. Phillips, Ed., *No Tillage Research Conference, Proceedings* (College of Agriculture, University of Kentucky, 1974).
8. G. B. Triplett, Jr., B. J. Conner, W. M. Edwards, *Ohio Report on Research and Development* (Ohio Agricultural Research and Development Center, Wooster, September-October 1978), pp. 70-73.
9. C. H. Slack, R. L. Blevins, C. E. Rieck, *Weed Sci.* **26**, 145 (1978).
10. K. C. McGregor, I. D. Greer, G. E. Gurley, *Am. Soc. Agric. Eng. Trans.* **18**, 918 (1975).
11. L. L. Harrold and W. M. Edwards, *J. Soil Water Conserv.* **27**, 30 (1972).
12. L. L. Harrold, G. B. Triplett, Jr., W. M. Edwards, *Agric. Eng.* **51**, 128 (1970).
13. G. W. Langdale, A. P. Barnett, J. E. Box, Jr., *Proceedings of the First Annual Southeastern No-Till Systems Conference*, J. T. Touchton and D. G. Cummings, Eds. (Georgia Experiment Station, Spec. Publ. No. 5, Experiment, 1978), pp. 20-29.
14. R. Lal, *Soil Sci. Soc. Am. J.* **40**, 762 (1976).
15. B. L. Schmidt and G. B. Triplett, Jr., *Ohio Agric. Res. Dev. Rep.* **52**, 35 (1967).
16. R. R. Allen, B. A. Stewart, P. W. Unger, *Soil Conserv. Soc. Am. Proc.* **31**, 111 (1976).
17. R. L. Blevins, D. Cook, S. H. Phillips, R. E. Phillips, *Agron. J.* **63**, 593 (1971).
18. J. N. Jones, J. E. Moody, J. H. Lillard, *ibid.* **69**, 719 (1969).
19. R. Lal, *Plant Soil* **40**, 129 (1974).
20. ——, *Int. Inst. Trop. Agric. (Ibadan, Nigeria) Tech. Bull. No. 1* (1975).
21. J. E. Moody, J. N. Jones, J. H. Lillard, *Soil Sci. Soc. Am. Proc.* **27**, 700 (1963).
22. L. R. Nelson, R. N. Gallaher, R. R. Bruce, M. R. Holmes, *Agron. J.* **69**, 41 (1977).
23. G. B. Triplett, Jr., D. M. Van Doren, B. L. Schmidt, *ibid.* **60**, 236 (1968).
24. W. W. Moschler *et al.*, *No-Tillage Corn: Current Virginia Recommendations. Extension Div. Publ. 342.* Virginia Polytechnic Institute and State University, Blacksburg, 1970).
25. U.S. Office of Energy Information, personal communication.
26. J. S. Steinhart and C. E. Steinhart, *Science* **184**, 307 (1974).
27. Soil Conservation Society of America, "Energy and conservation of renewable resources. A statement by the Soil Conservation Society of America" (Ankeny, Iowa, 1978).
28. Data from V. A. Bandel, personal communication.
29. H. Wittmus, L. Olson, D. Lane, *J. Soil Water Conserv.* **30**, 72 (1975).
30. J. N. Walker, in *Energy in Agriculture. Proceedings of a Conference-Workshop* (Southern Regional Education Board, Atlanta, 1975).
31. Council for Agricultural Science and Technology, *Potential for Energy Conservation in Agricultural Production, Report No. 40* (Iowa State University, Ames, 1975).
32. American Chemical Society, *Chem. Eng. News* **52**, 10 (1974).

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