FAO SOILS BULLETIN 33

soil conservation and management in developing countries

FOOD AND AGRICULTURE ORGANIZATION
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CONTENTS

I. INTRODUCTION

EXPERT CONSULTATION ON SOIL CONSERVATION AND MANAGEMENT IN DEVELOPING COUNTRIES

More than two-thirds of the world's population today are living in the developing world where agricultural production is not keeping pace with population increase. Increased food production could be achieved by expansion of cultivable areas, intensifying production by introducing high yielding varieties and introduction of new technology in agricultural production. The expansion of cultivable areas however, offers the least solution to the problem as most of the countries especially in Asia have little or no room for expansion.

A major problem facing the areas already under cultivation,thus aggravating the situation, is the seriousness of soil degradation and loss of soil fertility due to indiscriminate misuse of agricultural lands, forests and grazing lands. Soil conservation in the past was commonly equated with the mere prevention of erosion or with the restoration of areas in which accelerated erosion has already taken place. The modern thinking however, assigns to soil conservation a more comprehensive and more positive role, in that sustained improvement complemented by the preservation of available resources should form the central concept. Soil conservation is not merely a technical problem.

Several practices in agriculture today have resulted in misuse and degradation of previously fertile land. Bad cropping patterns, unsuitable cultivation techniques, misuse of tractor power, improper choice of implements and machines, the abuse of natural pastures and forests, the extension of cultivation to marginal and sub-marginal lands, and faulty irrigation and drainage systems are mostly responsible for the present situation.

In the attempt to solve some of these problems, many mistakes have been made resulting in failures and worsening of the situation in many developing countries. The basic concept of a multi-disciplinary approach to the solution of the problems has unfortunately been overlooked in most cases.

Detailed knowledge of the nature and distribution of land in an area are the basic pre-requisites of any conservation programme. In this regard, land inventories must be interpreted in practical terms, significant to all other aspects of the environment and to the basic requirements of all land-users and planners.

Soil conservation must not be limited solely to agricultural and grazing lands. Conservation of the forests is of equal importance as any misuse of such land will result in erosion, sedimentation and soil degradation of the whole watershed.

Conservation education and extension are areas where particular attention must be directed in the developing countries. Many countries transfer without due consideration to socio-economic factors, conservation education methods from other environments with the pious hope of solving their own problems.

The organizational set-up is often uncoordinated with the general machinery of other Government Departments. This has in many cases resulted in ineffective, disorganized programmes which failed or even, in some cases, perpetuated the problem. There are examples in many countries of expensive soil conservation structures which are not properly maintained and which result in a worsening of the situation. In many of these countries, techniques need not always be complex. Such simple practices as contouring and terracing, constructed with the farmers' own tools, may in the aggregate, contribute as much as the more spectacular large scale development.

The purpose of this Expert Consultation was to re-examine the whole question of soil conservation and management in the developing countries, bearing in mind socio-economic aspects, administrative structures, technology and financial resources. The discussions elucidated pertinent problems in the organization of soil conservation and management in these countries and possible solutions were suggested.

FAO placed great importance on the meeting, the results of which may help millions to preserve and improve their natural resources and sustain them for a more prosperous life.

It is against this background that the proceedings of the Expert Consultation are published in the series of FAO Soils Bulletins.

II. RECOMMENDATIONS OF THE WORKING GROUPS

INTRODUCTION

i. Soil erosion, and consequently the need for conservation, is not confined to land under arable use; it frequently affects grazing lands, and can be associated with mining, road construction, forestry and other kinds of land use.

ii. Soil conservation refers not only to mechanical protection measures but includes all aspects of land use planning, development and management which contribute to the maintenance and improvement of soil resources.

iii. Soil conservation is an interdisciplinary subject, which involves agronomy, soil science, range management, forestry, ecology, hydrology, engineering, geography, economics, sociology and other disciplines.

iv. Soil is a basic resource, for the present and the future. As such, the value of its conservation extends beyond that which can be expressed in monetary terms.

v. The damage caused by severe soil erosion is frequently irreversible. It is consequently desirable to take conservation measures to prevent onset of erosion rather than acting after it has commenced.

A. WORKING GROUP ON RESEARCH, EDUCATION AND EXTENSION

1. GUIDELINES ON RESEARCH

As a general principle it is suggested that the contribution of FAO should be directed towards the coordination and dissemination of results and assistance to individual countries; and that individual countries and institutions should concentrate on work related to their local or regional circumstances.

Certain branches of research in soil erosion and conservation are well-established, for example, experimental work on run-off plots. We by no means suggest that such work should be discontinued. It is necessary in order to provide fundamental scientific data, without which applied studies cannot proceed; furthermore, there is also a demonstration value to work of this nature. Nevertheless, as work of this kind already takes place in many countries, it is desirable that greater attention should now be directed towards other types of work, including the following:

i. Field studies, including mapping, of the location, extent and severity of erosion. In addition, it will frequently be necessary to collect the basic data required for the preparation of such maps, preferably using standardized procedures.

ii. Case studies of erosion and its causes, taking into account the effects of social, cultural and physical factors, land use and economic and institutional factors.

iii. Investigations of the effects of social and institutional factors in causing erosion or inhibiting conservation measures.

iv. The adaptation of techniques of soil conservation to the physical, economic and social conditions of particular countries and areas.

v. Studies of farming systems and methods of land management (e.g. cover crops, minimum tillage, agri-silviculture, agri-aquaculture) which are conservational and, at the same time, compatible with traditional land use practices.

vi. Attempts to quantify the consequences of erosion in productive and economic terms, and hence to demonstrate the benefits to be derived from conservation.

vii. Studies of different land use and management practices in relation to the development of sound soil conservation methods. Under this general head are included:

a. Different methods of land clearance and silvicultural practices;

b. The consequences of mechanization;

c. The effects of shelter belts and wind breaks;

d. The consequences for the soil of levels of intensity of use higher than those to which it had formerly been subjected (e.g. continuous arable use, grazing at high intensities).

viii. Investigation of rates of erosion on grazing lands, and relationships with plant and animal productivity.

ix. Studies of the off-site effects of erosion (e.g. on stream flow regimes, reservoir siltation).

2. GUIDELINES ON EDUCATION

i. An appreciation of soil conservation should be introduced as an aspect of "general studies" in secondary and tertiary education in the same way that students are made aware of their cultural heritage, their country's history, the principles of hygiene, etc.

ii. The study of soil conservation as a subject in its own right should be introduced into secondary and tertiary curricula, and soil conservation topics should be introduced into other subjects at primary level.

iii. The status of soil conservation as a professional discipline should be encouraged by higher degrees in Soil Conservation.

iv. Since there is a greater requirement for practical conservationists than for conservation research workers, higher degree training should put more emphasis on practical application of knowledge than on research.

v. The interdisciplinary nature of soil conservation education and training should be recognized. It cannot be contained entirely within a faculty of agriculture, or forestry, or engineering.

vi. In the case of higher degrees which have a significant research component, the research should certainly be relevant to the student's own country, and preferably carried out there.

vii. One of the most pressing needs is for more trained staff at technician level, i.e. the man who actually sets out the work in the field. Technical fellowships to provide short-term practical training at this level would be useful. Since the physical conditions vary from one country to another, training courses are preferably on-site training in the country concerned.

viii. The panel recognizes the difficulty which can arise when technicians or technologists attend courses and then return to take up positions under seniors who do not appreciate the training. Consequently, there is a need to ensure that in all soil conservation units the value of specialized training is recognized at all levels.

3. GUIDELINES ON EXTENSION

i. Extension services and soil conservation work

Recognizing that the implementation of soil conservation programmes requires special expertise covering many disciplines, and that this expertise is not normally available within an extension service, the recommendation of the Working Party on Institutional Organization is reiterated, i.e. that it is essential to have a separate soil conservation organization. As a short term measure, until such a soil conservation organization is established, it may be appropriate to form within the extension service a soil conservation unit or department which is made up of specially trained personnel. However, in the long term, the soil conservation operations of an extension service should be limited to follow-up, maintenance and simple soil conservation practices, with the planning and design of soil conservation programmes handled by soil conservation specialists.

ii. Extension programmes accompany soil conservation programmes

Since soil conservation programmes will not be effective without the understanding and willing cooperation of the land user, it is suggested that an extension service should include within its terms of reference the duty of explaining to land users the need and purpose of each soil conservation programme and the results to be expected. The use of demonstrations will be an important aspect of this work.

iii. General extension/education

In addition to extension work which is related to a particular programme, there should also be a general programme aimed at educating the land user in the philosophy of good land husbandry. While this general extension programme would be primarily directed towards the rural population, it should also have the long-term aim of generating awareness throughout the whole population.

iv. Extension techniques

The techniques for disseminating information on soil conservation are well known, and while the actual material and the details of the approach should be adapted to local circumstances, the basic principles are well tried and tested. Some of these are:

a. Use of the mass media to create general awareness (including TV, documentaries);

b. Use of specially prepared simple literature (e.g. the "comics" of the Soil Conservation Society of America);

c. Introduction of conservation topics into the school curriculum;

d. Use of youth organizations such as 4-H, Young Farmers, etc.

v. <u>Effective extension</u>

The effectiveness of an extension service, or an extension worker, should be measured by the extent to which the objective is achieved. The number of visits made, or the number of lectures, demonstrations, handouts, may have no relation to the effectiveness of the operation. In order that an extension service may operate effectively it must be adequately staffed, so that it is possible for an effective contact to be maintained between the extension worker and the farmers with whom he is dealing.

B. WORKING GROUP ON ORGANIZATIONAL AND FINANCIAL ASPECTS

i. Due to the rapidly progressive loss of land and water resources by erosion, urgent action is needed to take remedial measures in most developing countries.

ii. The present organizational and institutional set up in most developing countries cannot cope with the increasing needs for land and water conservation activities.

iii. Because of the multifaceted nature of the problem, special organizations should deal with the multidisciplinary character of soil and water services.

iv. To initiate effective action on this subject, a Soil Conservation Board at a high, policy-making level should be established in developing countries.

v. In countries where no related organizations exist, a secretariat should be formed under the Soil Conservation Board and be composed of high level technicians in the field of land, water, forestry and human resources. The secretariat should be established for initiation and coordination of soil conservation activities.

vi. In countries where some services in soil and water exist they should be given the status of a unified service. As a transitional step only, a Task Force may be established.

vii. The disciplines involved in such a unified Soil and Water Conservation Service will be identified below and should be used according to the agro-ecological zones as required:

a. Land evaluation
b. Ecology
c. Geography
d. Hydrology
e. Agronomy
f. Forestry
g. Soil and water conservation
h. Engineering
i. Social science
j. Soil and water conservation planning
k. Comprehensive watershed management
l. Agricultural production economics
m. Coordinated programmes with research, education and extension.

viii. <u>Policy</u>

a. Definitions of the required policies to achieve some of the identified soil and water conservation goals must be clearly stated.

b. Requisites: The need for remedial action based on recognized natural resources and environmental problems.

c. Statement of policy purposes that represent a consensus among the people involved in terms of what the policy should perform.

d. The policy should establish general guidelines and define the directions for achieving the goals.

e. Guidelines on the following lines of action should be delineated:

- Policy goals
- Flexibilities
- Implementation and innovation
- Planning, research and evaluation
- Peoples' participation
- Prevention of fragmentation
- Complementary of government roles
- Institutionalization of incentives
- Comprehensiveness of approach
- Land tenure

ix. Finances

a. Finances should be in the general programme of government activities, services and budgets.

b. In the framework of the development of this, serious consideration should be given to allocate sufficient funds for incentives to farmers for implementation of the field development programmes and assistance projects, field operations and maintenance.

x. FAO's role in establishing and developing multidisciplined soil conservation programmes in developing countries

a. To make governments aware of the urgency and the need to institutionalize the soil and water conservation programmes.

b. To catalyse in influencing the policy-making bodies in government to take effective action in this respect.

c. To advise how to create the basis for such activities by adequate legislation.

d. Such actions should be carried out in the framework of Regional Offices by country representatives and/or high level Headquarters staff.

e. Assistance in formulation and implementation of field programmes which will include on-the-job training.

f. Special attention should be paid to the planning and implementation of comprehensive watershed management on a small sub-watershed scale in representative areas.

C. WORKING GROUP ON PRACTICAL AND TECHNICAL ASPECTS

Practical/technical aspects in connection with FAO's projects on soil conservation

The discussions during the sessions of our expert panel this week have emphasized the great need for programmes of soil and water conservation in developing countries. The working group makes the following general suggestions to FAO and to governmental institutions cooperating in such programmes:

- better integration between disciplines and administrations involved;

- preference for small, high-impact conservation projects with active participation and follow-up by local decision-makers and farmers to avoid a collapse of the project when the expatriates leave;

- increased responsibilities from local government and less from donating agencies. It is of particular importance that after local staff are trained they should continue to implement the programme and not be transferred to other duties;

- more effective evaluation and follow-up of projects to utilize existing experience both within FAO and in the project areas. The evaluation should include socio-economic, ecological, technological and organizational aspects.

The working group structured the discussion in the following six steps of project planning, execution and follow-up. It is supposed that steps 2 and 3 are prepared by a mission of consultants to the country requesting assistance. The documents of steps 1, 2 and 3 should be carefully studied by the staff before implementation.

i. General problem identification: Request for assistance made by a developing country

The magnitude of the problem and scale of operation should be defined. In the approach to soil conservation in developing countries, the technical aspects to come under consideration should include protection of the environment and improvement of the conditions of life for the people involved, in addition to the purely technical matters on erosion control and improvement of production.

ii. Analysis of existing information

Local and traditional conditions in the project area: It is essential that more attention be given to local and traditional patterns and constraints. Political, administrative, socio-economic, demographical, ecological and technological conditions should be fully taken into account. The needs for further data collection and preparation for evaluation of project impact should be defined.

iii. Project formulation

In programme formulation more consideration must be given to projects leading to comprehensive programmes in the country, which must be followed-up by FAO, by the donating agency, and the local government, by technical servicing on a programme basis; terefore, the article of agreement must include statement of intentions of the government, its decisions on legislation and its commitment on follow-up after termination of the project. Such projects must emphasize proper biological conservation and management in addition to appropriate engineering techniques. Considering that soil conservation includes aspects of soil and water management, it usually involves high capital and human skill inputs and it is felt that more emphasis be given to approaches through plant and animal management for good land use in developing countries.

Preparation and funding for evaluation of project impact during and after execution should be included in the project formulation as well as necessary collection of further data. The educational input of the project should be planned and included in the formulation.

iv. Project implementation

Projects should be completed in appropriate time for good soil conservation and management. During the implementation the project should be divided into phases, each of which should demonstrate a tangible achievement. However, attention must be paid to maintain the goodwill, motivation and support of the local population. This would facilitate the follow-up and acceptance of the programme. The implementation should create a capable, well-motivated, multidisciplinary national team to carry on the programme during and after termination of FAO involvement.

v. Project evaluation

Repeated evaluations should be undertaken and used to correct, if required, planning and implementation. The project should be flexible enough to allow necessary modification.

vi. Project follow-up

An effective follow-up is the most essential component for the successful completion of the objectives of a programme. Follow-up should include maintenance of soil conservation treatments, servicing, training and extension, financed through a programme activity.

III. TECHNICAL PAPERS

A. Conservation Practices in Agriculture

Paper No. 1

SOIL CONSERVATION PRACTICES AND EROSION CONTROL IN INDIA - A CASE STUDY

by

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ABSTRACT

Erosion problems and conservation hazards through floods and droughts have occurred frequently over the centuries. Their effect on the national economy has been more acute in recent years. Owing to increasing human and livestock populations, and other developmental activities, competition for the land has become keen. By reviewing various factors, such as the land use distribution, hydrological and other soil group zones, floods, droughts and existing delineations of the country for various conservation purposes, India has been divided into ten compact Soil Conservation Regions. Considering the latest estimates of different types of erosion prevalent in various parts of the country, a composite soil erosion map has also been prepared.

The erosion problem has been examined for various soil conservation regions in conjunction with the flood and/or drought hazards, and critical socio-economic conditions. Rainfall intensity and the erosion ratio of the soil along with elevation and total rainfall have been collated and interpreted in order to study the soil conservation practices currently in vogue. Problems such as sheet erosion, gully and ravine erosion; torrent, stream/channel erosion; landslides and roadside erosion; coastal erosion; erosion due to shifting cultivation; and wind erosion are specifically discussed. Experimental results and field observations are used to illustrate the extent of hazards under different types of erosion in various soil conservation regions. Various practices now being advocated to treat different types of erosion, national efforts to preserve the life of multi-purpose reservoirs and to solve the problem of ravinous areas through an integrated programme of soil conservation on a watershed basis, are summarized.

SOIL CONSERVATION PRACTICES AND EROSION CONTROL IN INDIA - A CASE STUDY

1. INTRODUCTION

Soil erosion in India has been severe for centuries, but its impact on regional and national economy has only been acutely felt during recent decades. The high rate of population growth, both human (Anon, 1975) and livestock, (Anon, 1976 a), has resulted in over exploitation of natural resources to meet the ever-increasing demand for food, fodder and fuel. The increased competition on the same lands for these three essentials is resulting in widespread damage to our forests, pastures and wastelands as well as to fallow and agricultural lands. Thus increasing misuse of natural resources poses one of the greatest threats to better land use management, and the problem is compounded by competing demands from different sectors for expanding development and industrial activities on similar types of land.

Erosion problems in India, therefore, cannot be seen in isolation from natural calamities, viz. flood and drought, or without any reference to socio-economic conditions. An attempt has been made to present the erosion problems and the current efforts being made to solve them on the basis of broad soil conservation regions.

2. BACKGROUND INFORMATION

2.1 Land Use Distribution

Erosion problems vary according to the land use practices. The distribution of areas under various land uses is given in Table 1. Out of the total geographical area of 328 million ha, about 43.20% is cultivated and 20.02% is forest. The vast stretch of the Indo-Gangetic Plain, Deccan Plateau and Rajasthan Desert have very little forest. This poses not only an ecological and erosion problem but also aggravates the shortage of fuel and fodder. Barren and uncultivable wasteland constitute 9.07%, cultivable waste 4.81%, fallow land 6.23% and permanent grassland occupies 3.97% of the total area. The grasslands by and large are poor and over-grazed and so are the wastelands. Both suffer from high erosion hazard.

2.2 Hydrological Soil Group Zones

Hydrological soil groups give the relative ability of a soil to produce runoff and, therefore, to a considerable extent its susceptibility to erosion. These ratings have been determined for a large number of Indian soil series (Bali, Y.P., 1969) and based on them, India has been delineated into four hydrological soil group zones (Vandersypen *et al*, 1972). Areas having soils of "B" group constitute 53.60%, "D" 18.49%, "C" 16.82% and "A" 11.09% only (Fig. 1).

Table 1 DISTRIBUTION OF AREAS UNDER DIFFERENT LAND USES IN INDIA (1972–1973)

	Classification	Area in thousand hectares Break-up	Total	Percentage of total area Break-up	Total
1.	Area under forest		65 708		20.02
2.	Area not available for cultivation:		46 444		14.10
	i) Area under non-agricultural uses	16 571		5.03	
	ii) Barren and uncultivable land	29 873		9.07	
3.	Other uncultivable land including fallow land:		33 728		10.11
	i) Permanent pastures and other grazing land	13 079		3.97	
	ii) Land under miscellaneous tree crops and groves not included in net sown areas	4 358		1.33	
	iii) Cultivable waste	15 841		4.81	
4.	Fallow land:		20 565		6.23
	i) Fallow land other than current follows	8 173		2.47	
	ii) Current fallows	12 392		3.76	
5.	Net area sown		140 233		43.20
6.	Total reporting area		306 223		93.66
7.	Area for which no return exists		22 035		
8.	Total Geographical area		328 258		100%

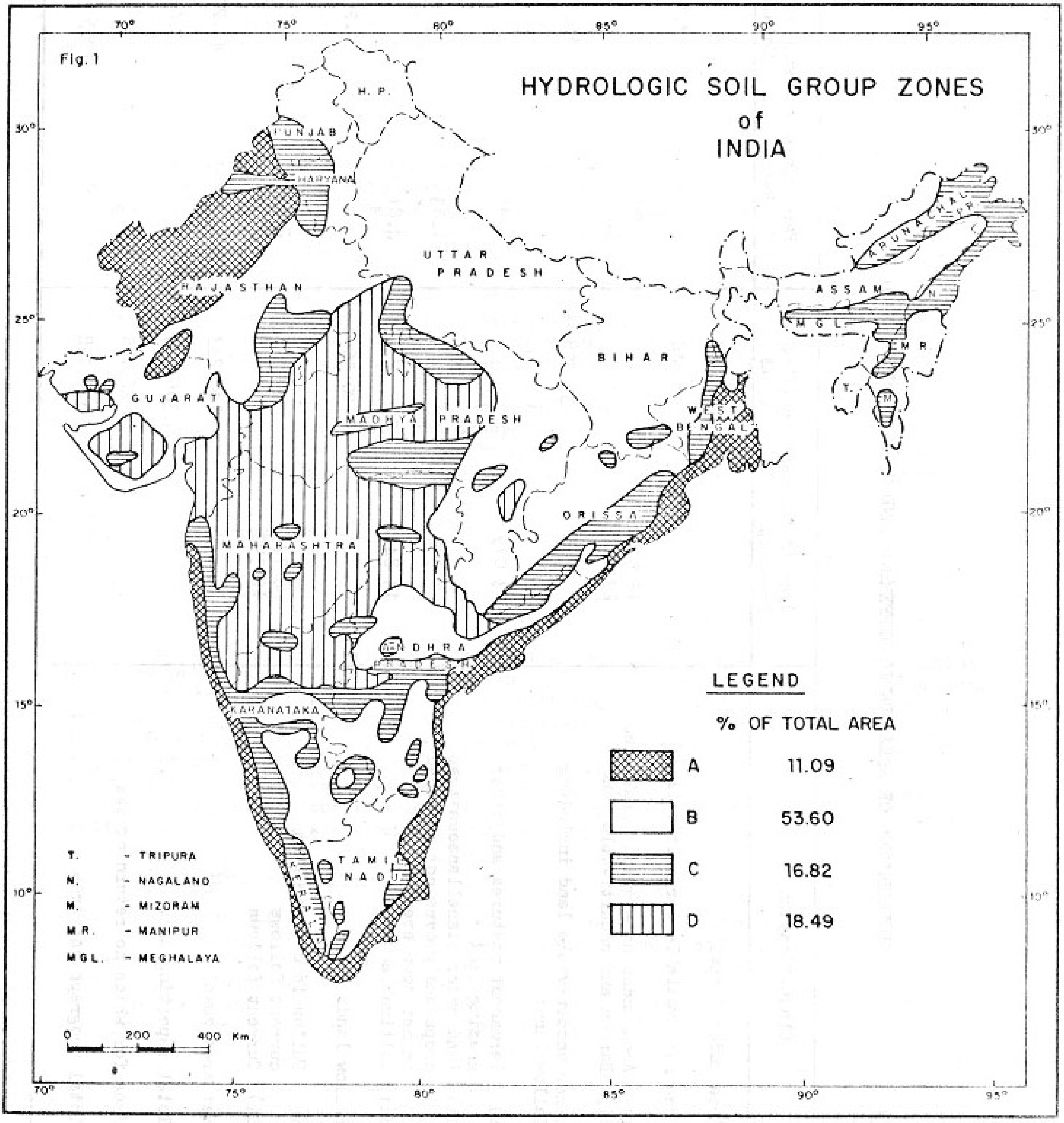
Fig. 1
HYDROLOGIC SOIL GROUP ZONES of INDIA
LEGEND
% OF TOTAL AREA
A 11.09
B 53.60
C 16.82
D 18.49
T. - TRIPURA
N. - NAGALAND
M. - MIZORAM
M.R. - MANIPUR
MGL. - MEGHALAYA
0 200 400 Km.
H. P.
PUNJAB
HARYANA
RAJASTHAN
UTTAR PRADESH
BIHAR
ASSAM
GUJARAT
MADHYA PRADESH
WEST BENGAL
ORISSA
MAHARASHTRA
ANDHRA PRADESH
KARANATAKA
TAMIL NADU
70°
75°
80°
85°
90°
95°
30°
25°
20°
15°
10°

2.3 Flood Hazard

Floods visit India every year and cause untold misery to an average area of 6.7 million ha, out of which 2.2 M ha are cropped. The total affected area is estimated to be 20 M ha. Annual estimated damage due to floods has been put at Rs. 1 260 million (One US $ = Rs. 9.15) out of which 70% relates to agricultural crops (Anon, 1971a and 1974a). Areas affected by flood are shown in Fig. 2.

2.4 Drought Hazard

Like floods, the country experiences drought every year. About 3 million people with their livestock migrate in search of new pastures (Anon, 1973). This migration has often resulted in excessive grazing and the consequent destruction of the protective vegetative cover, leaving the soil bare to the erosive action of both wind and water.

The role of drought in conservation land use management in India is very great. About 75% of the cultivated land is rainfed and produces 42% of the country's foodgrain. It is estimated that even after all irrigation potential is achieved, at least 55% of the cultivated land will remain rainfed (Anon, 1974b). Vast stretches of non-agricultural land in these tracts have scanty rainfall and are suited to grassland development and livestock farming. After reviewing many definitions and classifications, the climatic crop growth indices, limiting rainfall amounts for different growth levels and expressed as a ratio of rainfall to different evapotranspiration demands, have been used to delineate the country into four drought classes, as shown in Fig. 3 (Das et al, 1974).

A comparison of Fig. 2 and 3 and a study of Table 2 reveals that intriguingly the drought has not been a curse to arid and semi-arid (i.e. low rainfall) regions alone. Many areas, in spite of fair annual rainfall, face drought right within the main rainy season (George et al, 1973). Again, in spite of evergreen forest and grasslands, many parts, e.g., the Nilgiris, are subject to regular droughts (Shri Niwas et al, 1967; Das et al, 1971a).

3. SOIL CONSERVATION REGIONS

Many attempts have been made to delineate a number of zones or regions and sub-zones of areas for the formulation of plans for development and utilization of natural resources. Physiographically, India has been divided into four major divisions (Singh, 1971) and into six water resource regions (Khosla, 1949). It has also been divided into seven main hydrological zones with the problems caused by sedimentation in the multipurpose reservoirs to the soil conservation programme mainly in mind (Bali J.S. 1969). At the Soil Conservation Centre, Dehra Dun, considering major soil groups, vegetation classes, physiography, rainfall and availability of irrigation, the country has been divided into twenty land resource regions and 186 land resource areas (Gupta et al, 1970). Again, for studying soil erosion with a distinct bias toward geology, the country has been divided into five first order physiographic regions (Ahmad, 1973).

After reviewing all these existing delineations and keeping in mind the integrated approach for analysing soil erosion problems as well as for appreciating the current erosion control practices, the delineation made by Gupta et al, (1970) has been regrouped into ten major Soil Conservation Regions as shown in Fig. 4. The distribution of areas under various soil conservation regions along with the annual rainfall and temperature ranges as well as available data on intensity ratio (a measure of erosiveness of rain), and rilling hazard ratio (a measure of erodibility of soil) are presented in Table 2.

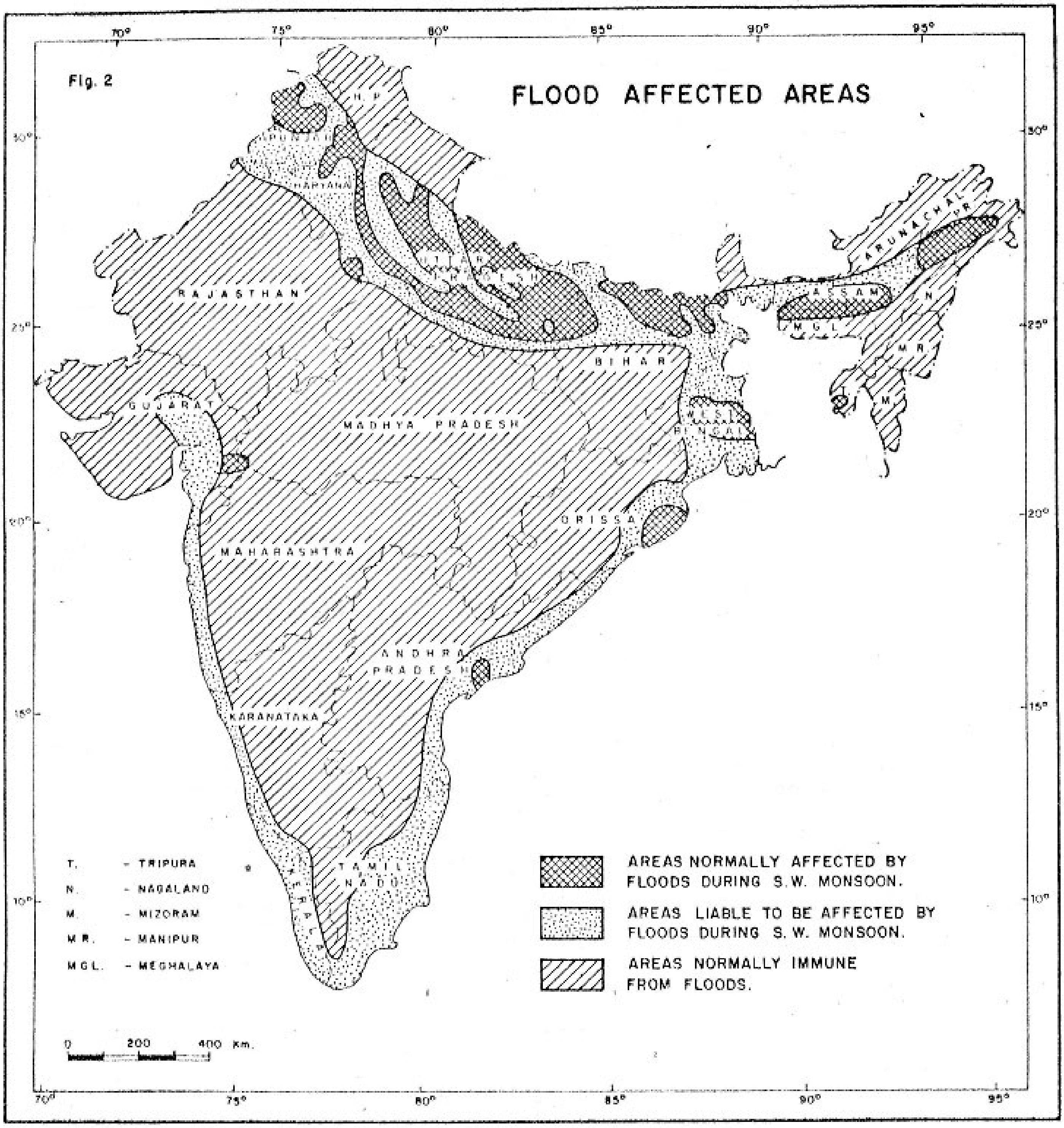

Fig. 2

FLOOD AFFECTED AREAS

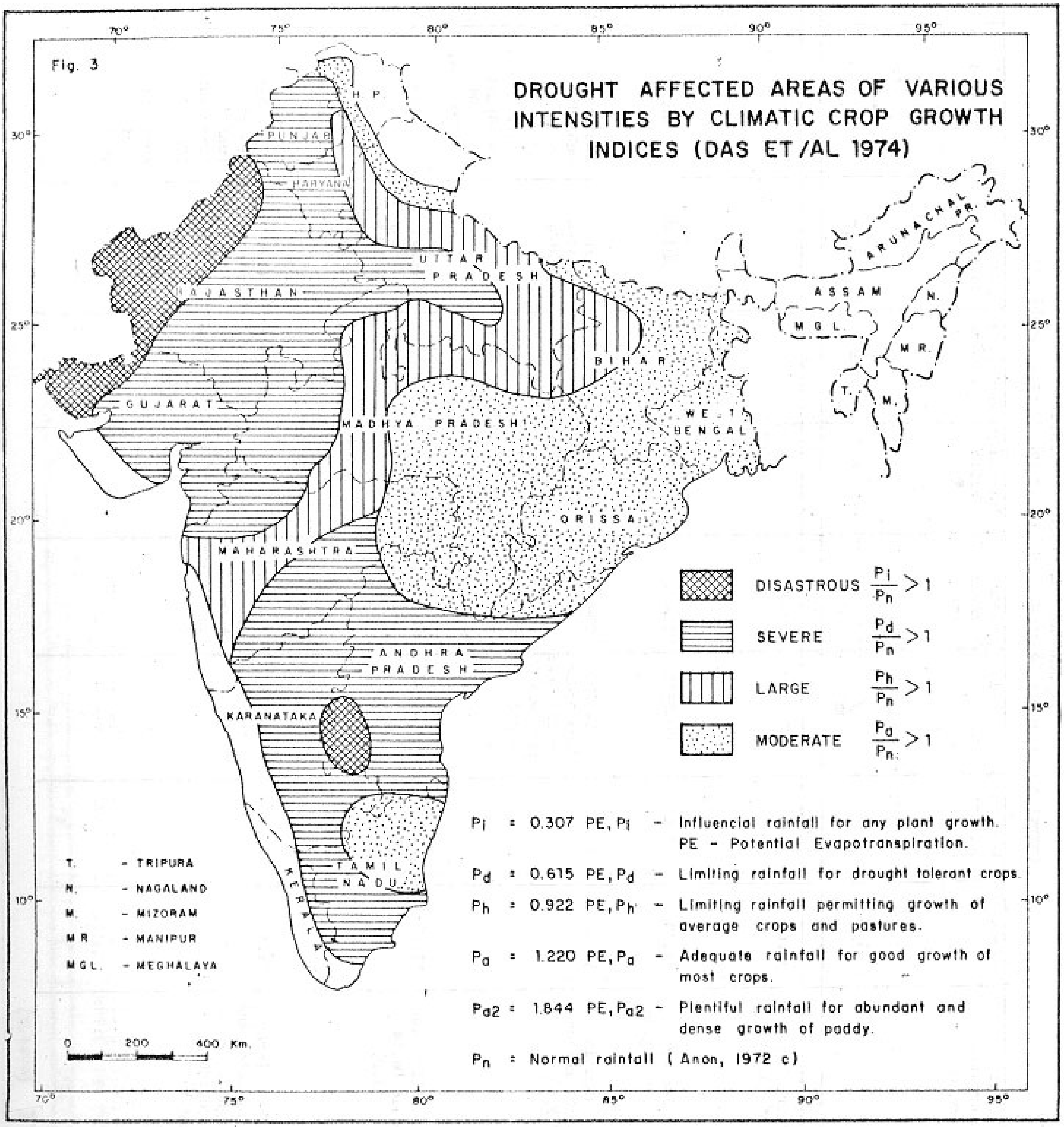
Fig. 3
DROUGHT AFFECTED AREAS OF VARIOUS INTENSITIES BY CLIMATIC CROP GROWTH INDICES (DAS ET/AL 1974)
H. P.
PUNJAB
HARYANA
RAJASTHAN
UTTAR PRADESH
BIHAR
GUJARAT
MADHYA PRADESH
WEST BENGAL
ORISSA
MAHARASHTRA
ANDHRA PRADESH
KARANATAKA
TAMIL NADU
KERALA
ARUNACHAL PR.
ASSAM
MGL.
N.
MR.
T.
M.
DISASTROUS $\frac{P_i}{P_n} > 1$
SEVERE $\frac{P_d}{P_n} > 1$
LARGE $\frac{P_h}{P_n} > 1$
MODERATE $\frac{P_a}{P_n} > 1$
P_i = 0.307 PE, P_i - Influencial rainfall for any plant growth. PE - Potential Evapotranspiration.
P_d = 0.615 PE, P_d - Limiting rainfall for drought tolerant crops.
P_h = 0.922 PE, P_h - Limiting rainfall permitting growth of average crops and pastures.
P_a = 1.220 PE, P_a - Adequate rainfall for good growth of most crops.
P_{a2} = 1.844 PE, P_{a2} - Plentiful rainfall for abundant and dense growth of paddy.
P_n = Normal rainfall (Anon, 1972 c)
T. - TRIPURA
N. - NAGALAND
M. - MIZORAM
M R - MANIPUR
M G L. - MEGHALAYA
0 200 400 Km.
70° 75° 80° 85° 90° 95°
10° 15° 20° 25° 30°

Table 2

SOIL CONSERVATION REGIONS OF INDIA
(particulars relate to erosion and other conservation problems)

S No.	Soil Conservation Region	Area 1/ M ha	Area as percent of total	Rainfall 2/ mm	Mean annual temp. 3/ C.	Intensity ratio * 4/	Rilling hazard ratio ** 4/	Hydrological soil group 5/ Fig. 1	Drought hazards (after climatic crop growth index) Fig. 3	Flood hazard Fig. 2
1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
1.	Northern Himalayan Region (A,B,C) 1/	34.60	10.66	200–2500	10–20	2.05 Dehra-Dun	2.13	B	None	None Except a pocket in Jhelum Valley
2.	North Eastern Himalayan Region (G,H)	17.70	5.47	1500–2500	10–20	–	–	B and C	None	–
3.	Indo-Gangetic Alluvial Region (D,E,F,L)	50.90	15.60	700–1100 Some areas in the West get less than 400	20–28	2.04 Agra 2.16 Boroda	7.0 reclaimed ravine Agra 5.0 Baroda 3.46 Ahmedabad	North West-C Rest-B	Eastern part subject to moderate drought; Central part to large; rest has severe drought	Normally affected
4.	Assam Valley and Gangetic Delta Region (I,P)	11.18	3.50	1500–2500	20–25	–	–	Assam Valley-C Gangetic Delta-A	None	Normally affected
5.	Rajasthan Desert, Runn of Kutch and contiguous semi-arid region (J and K)	23.85	7.31	150–500	25–28 and greater than 28 in extreme West	–	Dispersion ration 6/ 33–83% Rajasthan 31.4% Kutch 1.3–6.5 Kota 7/	Western part – A Rest – B	Rajasthan desert and Runn of Kutch subject to disastrous drought; Rest to severe	–

Table 2 (cont'd)

1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
6.	Mixed Red, Black and Yellow Soil Region (M)	11.57	3.58	600–700	20–28	1.83 Kota	1.31 Kota 4.57 Sawai, Madhopur	B	Centrally located part affected by large drought and eastern part by severe drought	-
7.	Black Soil Erosion (N)	67.45	20.63	Outer part between 600–750 Inner part 500–600	20–28	2.36 Bellary	4.49–4.79 8/ Jabalpur 1.80 Bellary 6.14 Dharwar	D	North East part large; Rest severe hazards	-
8.	Eastern Red Soil Region (O)	57.45	17.55	1000–1500	20–25	1.73 Midnapur	1.78–4.10 Raipur 2/ 2.5–21.60 Gullied area, Midnapur 9/ 1.09 Midnapur; 4.23 Santhal Pargana	B Mostly a belt behind East Coast C	Moderate hazard	Damodar River
9.	Southern Red Soil Region (R)	34.77	10.62	around 750	20–25 (10–15 in the Nilgiris)	1.73 in the Nilgiris	1.00 Minimum (Hyderabad, the Nilgiris)	Mostly B A belt behind West coast and patches C; small pockets D	A belt along the Western Ghat and also East part exposed to moderate one. Rest exposed to severe drought	Normally free
10.	East-West Coastal and Islands Region (Q,S,T)	16.20	12.60	East coast about 1000	20–25	-	-	A	West coast and most islands free from drought; central liable to large	Subject to flood hazard
		325.67	100.00							

* Intensity Ratio 4/ = $\frac{\text{Intensity for 5 minutes for 10 years recurrence}}{\text{Qualifying intensity for 5 minutes} = 7.63 \text{ cm/ha}}$

** Rilling Hazard Ratio 4/ = $\frac{\text{Erosion ratio of soil of an area}}{\text{Limiting safe value of erosion ratio} - 10}$

1/ after Gupta et al, 1970
2/ Anon, 1972b
3/ after Swaminathan, 1973
4/ Das et al, 1971; Das, 1976
5/ Vandersypen et al, 1972
6/ Gupta, R.S. 1958
7/ Mehta et al, 1958
8/ Ballal, 1954
9/ Bhattecharya, 1957

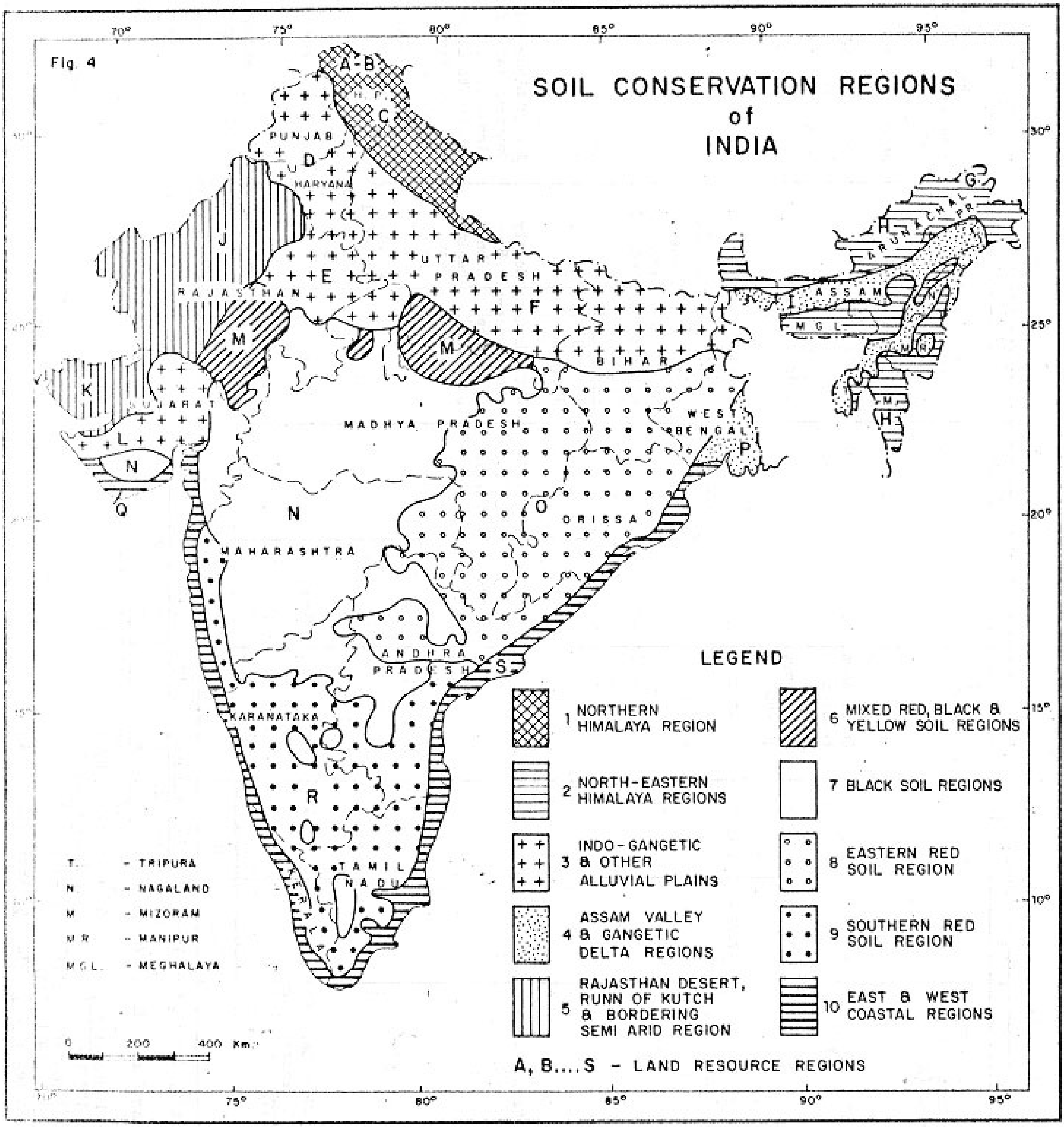
Fig. 4
SOIL CONSERVATION REGIONS of INDIA
PUNJAB
HARYANA
H.P.
RAJASTHAN
UTTAR PRADESH
BIHAR
GUJARAT
MADHYA PRADESH
WEST BENGAL
ORISSA
MAHARASHTRA
ANDHRA PRADESH
KARANATAKA
TAMIL NADU
KERALA
ASSAM
ARUNACHAL PR.
MGL
LEGEND
1 NORTHERN HIMALAYA REGION
2 NORTH-EASTERN HIMALAYA REGIONS
3 INDO-GANGETIC & OTHER ALLUVIAL PLAINS
4 ASSAM VALLEY & GANGETIC DELTA REGIONS
5 RAJASTHAN DESERT, RUNN OF KUTCH & BORDERING SEMI ARID REGION
6 MIXED RED, BLACK & YELLOW SOIL REGIONS
7 BLACK SOIL REGIONS
8 EASTERN RED SOIL REGION
9 SOUTHERN RED SOIL REGION
10 EAST & WEST COASTAL REGIONS
A, B....S - LAND RESOURCE REGIONS
T. - TRIPURA
N. - NAGALAND
M. - MIZORAM
M.R. - MANIPUR
M.G.L. - MEGHALAYA
0 200 400 Km

4. SOIL EROSION

4.1 Past Estimates

There seems to have been no coordinated attempt to document the incidence of various types of erosion and their extent and distribution throughout the country. In the late forties Kaith et al, (1948) submitted a brief report to this effect which urged consideration of the problems and their solution on the basis of natural units. Later on the Planning Commission (Anon, 1964) made a quick estimate of agricultural land subject to erosion, while the Working Group on Soil Conservation of the Fourth Plan (Anon, 1966) attempted to estimate the extent of erosion and other conservation hazards on all types of land. Bali 1974 outlined the distribution of areas under various conservation hazards with specific stress on the erosion problem and sedimentation of multi-purpose reservoirs. According to his estimate, a total of 175 million ha can be considered susceptible to erosion. In another attempt, while giving the macro view of land and water management problems in India, Vohra (1975) indicated that 140 million ha are seriously affected by water and wind erosion. Ahmad (1973) gives some detailed estimates of areas subject to various types of erosion.

4.2 Extent of Different Types of Erosion

The National Commission on Agriculture (1975b) provided the latest estimate on the basis of available information from various sources. Many parts of the country are subject to more than one type of erosion. The extent of erosion has been estimated as follows:

	(Million ha)
Total Geographical area	328
Total area subject to serious water and wind erosion	150
Area at critical stage of deterioration due to erosion	69
Area subject to wind erosion	32
Area effected by gullies and ravines, about	4
Area effected by shifting cultivation, about	3
Area under rainfed farming (non-paddy)	70

4.3 Erosion Map

On the basis of various erosion maps prepared by Ahmad (1973) and with the necessary modifications called for by the latest figures available, a composite map of India showing the extent of various types of erosion is presented in Fig. 5.

5. SHEET EROSION

Sheet erosion exists almost throughout the country. Areas subject to sheet as well as gully erosion and areas subject to notable sheet erosion only are indicated specifically in Fig. 5. It has been estimated that about 6 000 million tonnes of soils are eroded every year from about 80 million ha of cultivated lands; about 6.2 million tonnes of nutrients (2.5 of N, 1.5 million t of P and 2.2 million t of K) are carried away. The nutrients lost in this way are much greater than the quantity that we are using at present (Swaminathan, 1973). The different rates of soil loss under various land uses in different regions are given in a recent compilation (Tejwani et al, 1975), and the figures were obtained from ICAR research stations.

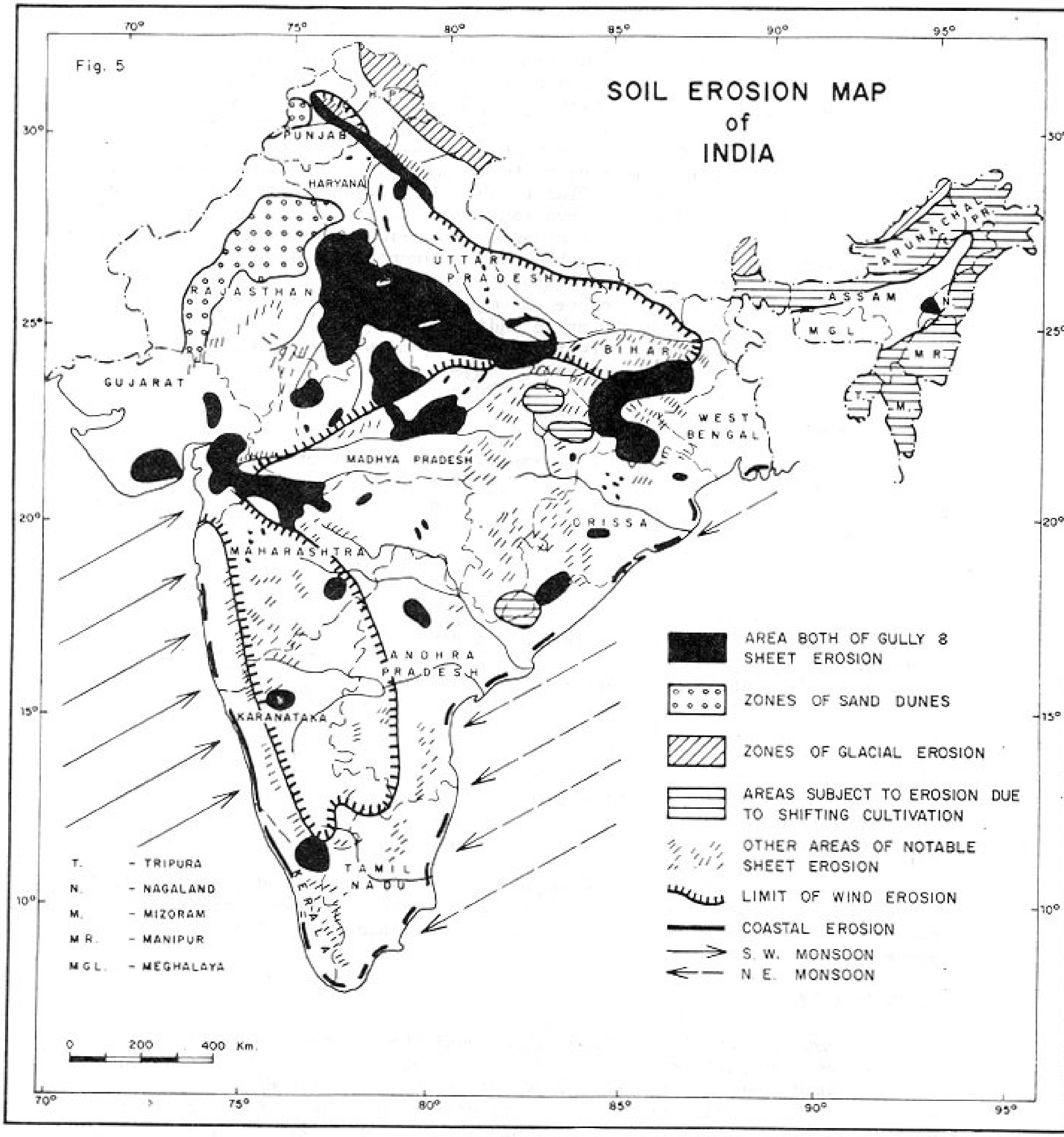
Fig. 5
SOIL EROSION MAP
of
INDIA
PUNJAB
H.P.
HARYANA
RAJASTHAN
UTTAR PRADESH
BIHAR
WEST BENGAL
GUJARAT
MADHYA PRADESH
ORISSA
MAHARASHTRA
ANDHRA PRADESH
KARANATAKA
TAMIL NADU
KERALA
ASSAM
ARUNACHAL PR.
MGL
MR.
N.
T.
M.
AREA BOTH OF GULLY & SHEET EROSION
ZONES OF SAND DUNES
ZONES OF GLACIAL EROSION
AREAS SUBJECT TO EROSION DUE TO SHIFTING CULTIVATION
OTHER AREAS OF NOTABLE SHEET EROSION
LIMIT OF WIND EROSION
COASTAL EROSION
S. W. MONSOON
N. E. MONSOON
T. - TRIPURA
N. - NAGALAND
M. - MIZORAM
MR. - MANIPUR
MGL. - MEGHALAYA
0 200 400 Km.
70°
75°
80°
85°
90°
95°
30°
25°
20°
15°
10°

5.1 Performance of Conservation Practices

The conservation treatments meant to reduce or prevent sheet erosion while achieving the desired moisture conservation and/or runoff disposal, range from contour farming to bench terracing. The performance of different conservation practices for controlling sheet erosion has been evaluated at a number of research stations (Tejwani et al, 1975) and also reviewed elsewhere (Das, 1974). To illustrate the relative effectiveness of a few practices, the results from the Nilgiri hills in the southern red soil region are given. On these hill slopes, that have lateritic soils, up and down cultivation of potato caused a soil loss of 39 t/ha/year whereas nutrient losses were Rs 333/ha (at the market price of 1967). Simple contour cultivation reduced the soil loss to 15 t/ha/year and nutrient losses to Rs 130/ha. When the cultivation was on non-paddy benches the soil loss was reduced to about 1 t/ha/year and the nutrient losses to Rs. 10/ha/year (Raghunath et al. 1967).

Terracing is by far the most effective and widely practised field measure for controlling or preventing erosion in different soil conservation regions. Terracing has also been adapted in different ways to meet varied physiographic and climatic conditions. In a general way, it can be defined as a series of mechanical barriers across the land slope to break the slope length and also to reduce the slope degree wherever necessary. On the steeper hill slopes there are graded (non-paddy) or levelled (paddy) benches constructed by restricted levelling and with provision for disposal. The system also applies to lower slopes where it is developed by raising bunds and then achieving the levelling through puddling. For rolling and flatter lands, with high rainfall, the system means graded bunds or banks (narrow base graded bunding) and for lands with scanty or erratic rainfall, narrow base (level) terracing (contour bunding) is practised to conserve moisture as well as reduce soil erosion. For better moisture conservation on larger areas as well as for control of soil erosion, it was observed that land treatment between the bunds, e.g. partial levelling (Saha and Patel, 1970) or cultivation along the contour, offers better protection as well as moisture conditions for higher production. For rolling lands and hill slopes with inadequate soil depth, graded trenches or contour trenches are used for forestation or plantation crops like tea or coffee. Field as well as experimental data show thatterracing controls runoff, checks soil erosion, helps to improve moisture conservation, groundwater storage and crop yields (Satpute, 1972; Das, 1974).

Treatments vary considerably from region to region, for instance, the high slopes of the Northern Himalayas are being put under good forest cover through afforestation and better forest management.

5.1.1 Narrow base terracing (bunding)

The Indo-Gangetic alluvial plains have an erosion intensity ratio value of about 2, whereas the rilling hazard ratio varies from 3 to 7. A sizable part of the region is liable to regular flooding as well as moderate to severe drought (Table 2, Fig. 2 and 3). The problem is, therefore, one of erosion control, disposal of runoff and conservation of moisture. Contour bunding, or narrow base terracing on the contour, at a suitable spacing and of a suitable cross section, is widely used to remove excessive runoff resulting from high intensity storms and surplussing arrangements are made wherever necessary.

The eastern red soil region has an intensity ratio around 1.73, whereas the rilling hazard ratio ranges from 1.09 to 4.23. The region is subject to almost recurrent moderate drought in spite of good rainfall (George et al, 1973). The southern red soil region, on the other hand, has a similar intensity ratio but generally a low rilling hazard ratio. However, the region is by and large subject to severe drough hazards (Fig. 3 and Table 2). Contour bunding with a surplussing arrangement often proves adequate. A typical contour bund cross section with a loose rubble wasteweir is shown in Fig. 6. Small tanks for storing and utilizing water for paddy cultivation on benches are also extensively used.

Fig. 6 Contour bunding (narrow base terrace on contour) with dressed rubble wasteweirs, in black soil region (shallow black soil)

The black soil region has a very high intensity ratio (2.36) and the rilling hazard ratio ranges from 1.3 to 6.14. The north-east of the region suffers from large droughts whereas the rest to severe ones (Table 2, Fig. 3). The problem is not only to conserve moisture, but also to remove excess rainfall which cannot infiltrate due to low intake rates. The accumulation of water on land causes damage to the standing crops besides resulting in mechanical failure of the bunds and other structures. In the northern part of this region, the removal of excess water facilitates a more flexible rainy season crop and gives the possibility of using the excess water to grow a profitable winter crop. On the rest of this region, the rainfall is low and erratic; this area remains fallow during the main rainy season and thus subject to heavy erosion. Contour bunding has not been effective in the region (Das, 1974).

The latest findings in the black soil and the semi-arid southern red soil region indicate that some sort of graded bunding (graded narrow base terracing) with small ponds for storage and reuse of the runoff water for assured cultivation is more effective. Cultivation of crops on broad ridges and furrows seems to hold promise for these regions where stress is laid on saving crop residues, proper tillage and water harvesting besides erosion control (Anon, 1974b and Krishnamoorthy et al, 1974). The different types of small ponds which could be used on existing farm holdings are being tried presently at the All India Coordinated Dry Land Research Centre as well as the International Crop Research Institute for Semi-Arid Regions. Some possible changes in the design details for higher capacity-cost ratio have been developed by Sharma and Kampan (1975).

5.1.2 Design details for bunding

The spacing of the narrow base terraces can be more rationally determined from the modified Stewart or Ootacamund formula. It provides more flexibility over space and time and involves easily determinable factors as compared to the adjusted empirical formulae in use. The formula is:

$$\text{Vertical Interval} = \text{V.I.} = \frac{\sqrt{2s}}{2n}\text{, m}$$

$$\text{and Horizontal Interval} = \frac{50}{n(\sqrt{s})}\text{, m}$$

Where,

s = Average slope percentage
n = I.R.P.C.
I = Intensity Ration (defined at the foot of Table 2)
R = Rilling hazard ratio " " " ")
P = Proportionate protection offered by supporting conservation practices
C = Proportionate protection offered by cropping management.

The formula is also applicable when trenching.

Concerning the cross-section, the design depends upon the amount of excess rainfall and the depth of impounding desired upstream of the terrace. In the case of graded bunding, it is the channel that is more important and the downstream bund is a spoil bund. For the semi-arid southern red soils 0.2% longitudinal gradient was found to be effective, whereas for the Northern Himalayan foothills the gradients of 0.4 and 0.6% were found to be equally good (cited from Das, 1974).

There are different types of structures; for removing excess rainfall from bunded areas some of the common ones are given in the book, Soil Conservation in India (Rama Rao, 1972). They are:

1. prefabricated escapes
2. dressed/undressed loose stone wasteweirs with end pitching
3. ramp-cum-weir
4. pipe outlets
5. ringwell and pipe outlets
6. channel weir
7. stone/brick masonry low drops/chutes

5.1.3 Paddy and non-paddy bench terracing

In the Northern Himalayas, paddy crops are raised on bench terraces. There are also traditional irrigation systems using the hill streams. In the southern hills, namely, the Nilgiris, lying within the southern red soil zone, a system of non-paddy benches has been developed (Lakshmipathy and Narayanswamy, 1956) see Fig. 7. These benches are provided with a longitudinal gradient to drain into cross disposal drains. The vertical spacing is determined by the depth of the cut available and from the formula $VI = 2 (T - 0.15)$ m, where T is the depth of productive soil in meters; VI, computed as above, is again tested with the minimum width vis-à-vis the land slopes and ease for farm operations (Lakshmipathy and Narayanswamy, 1956). For effective runoff disposal as well as better moisture conditions, these benches should not be longer than 100 m (Das, 1974), whereas they can have a longitudinal gradient upto even 1% under Nilgiri conditions (Kurian et al, 1975). In the Northern Himalayan regions, non-paddy benches of the southern type are being introduced. However, due to heavy rainfall, a more elaborate disposal system is being provided.

On the steep Himalayan slopes, narrow benches are being constructed to raise belts of orchard trees. Such benches are also recommended for raising other plantation crops, and medicinal plants.

5.1.4 Developing low cost bench terracing

Even though there is no substitute for bench terracing when growing crops on hill slopes, it is expensive and initial crop yield is low due to disturbance of the top soil. In order to obviate these disadvantages, benches could be developed over years behind graded barriers of grass, or earthen bunds or stone walls. A typical bench developed behind the graded barrier of *Tripsacum laxum* is shown in Fig. 8. In Kerala, benches are developed by putting earthen bunds with downstream pitching across the land slope, whereas in the northern Himalayan region, as well as in the low hills of the eastern red soil region, benches are developed by building stone risers (Murthy, 1969).

5.2 Vegetative Stabilization of Conservation Measures

All bund channel sections as well as the riser face of benches are stabilized with grass. On locations subject to hot winds Eucalyptus, and *Eulaliopsis binata* grass or *Ricinus communis* are grown on bunds and they provide an additional income over years besides serving as wind breaks (Singh and Srivastava, 1973; Tejwani et al, 1975).

6. GULLY AND RAVINE EROSION

This is possibly one of the most spectacular types of erosion. Ravines annually ravage 8 000 ha throughout the country where approximately 0.5% of the ravine catchment area is being eroded. Annual damage to the tablelands accounts for Rs 40 million (Anon, 1972a). Gullies and ravines damage land, habitations, roads, railways and other public properties, thus adversely affecting rural economy (Anon, 1976b). A typical picture of gully erosion is shown in Fig. 9. They also provide shelter to unsocial elements causing law and order problems. The ravines are mostly found along the rivers of Jamuna, Chambal, Sabarmati, Mahi, Gumoti and in the catchments of the Mayurakshi, Kangasabati in the eastern red soil region. Generally, ravines originate within a short distance of the river and

Fig. 7 Bench terracing (non-paddy) in the southern red soil region of the Nilgiri hills (photo P.K. Thomas)

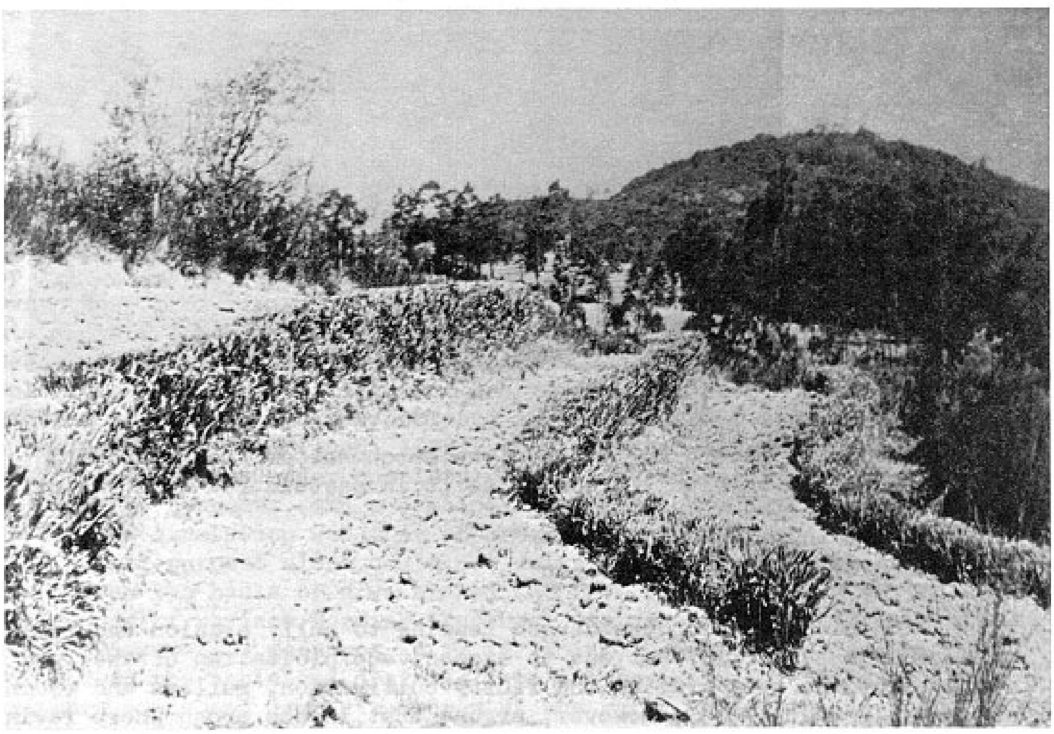

Fig. 8 Developing non-paddy benches along the graded strips of Tripsacum laxum on the slopes of the Nilgiri hills

near or around the confluences of two channel flows. At a conservative estimate, the country is losing a total output of 3 million tonnes of foodgrains annually due to degradation of land through gullies and ravines (Anon, 1972a).

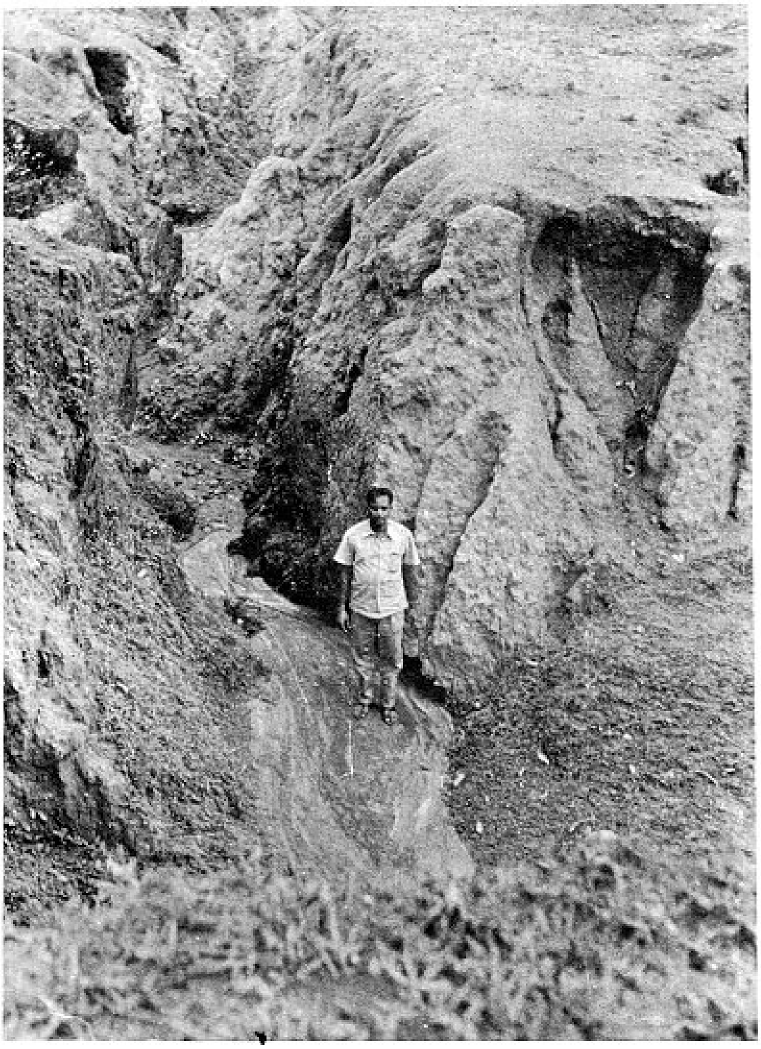

Fig. 9 Severe gullying in the catchment of the Mayurakshi on highly erodible soils in eastern red soil region

6.1 Formation of Gullies and Ravines

Opinions vary on the causes leading to gully erosion and ravine formation. The popular belief is that due to excessive exploitation of the land by continuous deforestation, over grazing and faulty cultivation, gullies and ravines have formed. Ahmad (1973), however, argues that in the areas where ravines are very severe there has not been luxurious vegetation in the recent past. The areas subject to severe gully erosion are located in western, central and eastern India and along the foothills of the Himalayas. The difference in elevation of these areas ranges from near sea level in the west to about 300 - 1 000 m in the east In the foothills of the Himalayan region, gullies are being found at elevations as high as 1 000 - 1 300 m. The type of soils, rainfall received and topographical features are also considerably different in these major regions where gully and ravines are found extensively. Table 2 reveals that in the ravines in western India, the intensity ratio is 2.16 whereas the rilling hazard ratio is between 3.46 and 5. The bulk of the ravines in Central India are in the Indo-Gangetic alluvial region and have an intensity ratio of 2.04 and rilling hazard ratio for ravinous areas as high as 7. A part of the ravine system in central India falls in the black soil region as well as in the mixed red, black and yellow soil region. In the latter region, the rainfall intensity ratio is 1.83 whereas the rilling hazard ratio ranges from 1.31 to 6.5. In the red soil region of eastern India, where ravines are very conspicuous, the intensity ratio is 1.73 and the rilling hazard ratio is high, Ahmad (1973) contends that the incidence of gully and ravine erosion is possibly due to geologic uplift. Roy and Mishra (1969), from their field observations, concluded that ravines are a function of depth of the river and are invariably confined to the vicinity of rivers and tributaries. Gully is a function of overland flow and therefore, of catchment characteristics alone, whereas ravine is primarily a function of channel flow and its ingress into the catchment. They hold the view that the ravines proceed from the river or tributaries to the agricultural lands.

6.2 Treatment

Considering the complex physiographic background of the regions where gully and ravine erosion are prevalent and the involvement of socio-economic aspects, attempts have been made to take appropriate action to control this erosion as well as to restore the land to better land use management. The earliest attempts were made in the erstwhile Gwalior State in 1919, there revenue concessions were granted to cultivators who would reclaim the ravines along the Chambal, (Rege and Yash Pal, 1973). In the post-independence years, the Government of Uttar Pradesh and Madhya Pradesh took a number of pioneering steps to control and reclaim ravines along the Jamuna and Chambal (Anon, 1971b; Rege and Yash Pal, 1973).

6.2.1 Central pilot projects

During the Fourth Plan, Pilot Projects were started in the four major States covering the ravinous areas of western and central India to develope suitable technology for reclamation and control of ravines for agriculture and horticulture and for stabilizing deeper ravines. During the Fifth Plan, the Pilot Projects were extended to more locations to cover the varied physiographic and climatic conditions prevalent in the catchments of different rivers and also to test the feasibility of the technology as well as the viability of the economics of ravine control, reclamation and the stabilization programme. The entire concept for tackling this programme was outlined in the Report of the Working Group on Ravine Reclamation (Anon, 1972); they examined alternatives, e.g. putting the ravines under complete vegetation and reclaiming them for agricultural purposes, and a combined programme on a definite watershed basis. The conclusion was that afforestation alone or reclamation for agricultural purpose alone could not solve the problem. It needs to be solved from the basis of a watershed and from the tablelands to the confluences of ravines forming a natural drainage system. As a result, normal conservation measures, e.g. terracing, bunding, etc. are being provided on the tableland draining into the ravines. By building periphery bunds and drop structures at the gully heads, the ingress of the gullies into the tablelands is being arrested while providing safe ways to take away the runoff through the ravine system. Shallow ravines, up to a depth of about 2 m are being reclaimed for agricultural and horticultural purposes where irrigation could be provided and cash crops grown (Fig. 10). Deeper ravines with steep sides are being stabilized with the help of vegetation and engineering structures of various types (Fig. 11).

Fig. 10 Reclamation of shallow ravines for agriculture with field irrigation channels along the Chambal in the mixed black, red and yellow soil region (photo Y.P. Bali)

Fig. 11 Ravines along the Chambal River, near Kota, in the mixed black, red and yellow soil region. Deep tail gullies and ravines are being put under afforestation (photo Y.P. Bali)

Fig. 12 Controlling erosion and restoring gullied lands by creating small ponds and developing paddy benches in the Mayurakshi catchment in the eastern red soil region

In the eastern red soil region gullied areas are being reclaimed by putting earthern checkdams in a series or singly to develop micro storage ponds (Fig. 12). On the downstream side of the storage, paddy benches are developed. Incidentally, this system ensures holding up most of the potential sediment in a zone where soils have a rilling hazard ratio as high as 21.00. The system improves the productive capability of the area and thus encourages considerable cooperation by the people.

6.3 Performance of Treatment

The effectiveness of various treatments is being tested at research stations as well as on the Pilot Projects. The combined package of practices on the watershed basis have, by and large, been found effective. In the eastern ravines engineering and biological measures increased rain water retention by 53% (Singh and Dayal cited from Anon, 1974c). In western as well as central India the system of treating ravine watersheds with a combination of biological and engineering measures e.g. raising fuel fodder plantations, constructing peripheral bunds, drop structures, etc. resulted in a reduction of the peak discharge as well as soil loss over the years. More information about different types of structures, construction of bunds, selection of grasses and trees which have been found suitable for the purpose, through experimentation at research stations, are given in detail in an ICAR publication (Tejwani et al, 1975).

Regarding the economics of ravine reclamation, an evaluation report on the U.P. showed that by reclaiming the ravine areas for agriculture, yield could be increased by 16% (Anon, 1971b). The analysis of the integrated project outlined in another report (Anon, 1972a) indicated that the annual direct benefit from the seven year plan for 330 000 ha would be at the rate of 11.2% on the investment. This project would create employment opportunities to the tune of 339 million man days. The economic viability from the areas treated with grass, areas reclaimed for agricultural purposes and areas stabilized by afforestation, have also been analysed at ICAR research stations. It was observed that the investment in treating gullies, including reclaiming the areas, could be recovered within a period of 2-10 years (Tejwani et al, 1975).

Ravines affect habitations, communications and the agricultural productivity of regions where sizable populations are located. Any improvement measures for the area, even on the basis of watershed, therefore require the closest involvement of the people, i.e., beneficiaries, for their maintenance and appropriate follow-up actions not only in respect of agricultural lands, but also in respect of the deep ravines which will be put under fuel-cum-fodder plantations. If the areas are not treated with a view to providing appreciable economic returns to the beneficiaries, any treatment is likely to meet with ultimate failure. On the other hand, Kamnavar et al, 1975) observed that 3% of the initial investment would be required for maintenance and to stabilize the treatment measures during the first two years; in subsequent years it would be nominal. The cost of maintenance could easily be met from the sale of produce, such as grass, fire-wood, etc. from the treated area. Keeping this in mind, the National Commission on Agriculture recommended emphatically that the economic conditions should not be the sole basis in the reclamation of ravine lands. Poverty and the objective of curbing the activities of antisocial elements should receive due consideration. Ravine reclamation as such, should receive national priority and investment should not be denied on account of an unfavourable benefit cost ratio (Anon, 1976b).

7. TORRENT AND STREAM CHANNEL EROSION

7.1 Torrents

The problem of torrent erosion, in both the foothills of the northern Himalayan and the north-eastern Himalayan region, has been increasing. In the former, the torrents are popularly known as 'chos' and the rate of their progress can be realised from the data given by Kaith et al, (1948):

1852	– 194 km^2	for the Hoshiarpur district of Punjab alone
1896	– 286 km^2	
1939	–2 000 km^2	

The National Commission on Agriculture (1976b) observed that the devastation by 'chos' in the Punjab alone is over 2.5 million ha. Similar information for the north-eastern Himalayan region is not available.

7.1.1 Cause and approach for treating torrents

The main cause of the problem is the high runoff down the hill slopes with heavy silt loads that fill up the channel beds thereby reducing their capacity to carry the runoff and sediment. In consequence, the flow shifts from the original course. The process is repeated many times until vast stretches of fertile land are criss-crossed by courses swamped with coarse sediments and detritus. The 'chos' break up habitations, affect communications, agriculture, recharge of shallow wells and other social amenities.

The solution, lies in regulating the quantum of runoff coming down the hill slopes and the accompanying silt load (Pathak, 1975). Treatments must therefore cover measures in the catchment to moderate the runoff peak and volume and to reduce the soil erosion and consequent silt load. The main package of ameliorative practices include afforestation and grassland development with trenching across the land slope and growing agricultural and horticultural crops on terraced lands. As far as the main torrent is concerned, remedies are:

i. control of grazing and deforestation;

ii. protection of banks from erosion by providing marginal bunds at a reasonable distance from the edge; for sections subject to serious erosion, 'riprap' or loose retaining walls can be used;

iii. construction of rivetments, spurs and jetties to confine the flow and protect the bank from scouring. Training walls, made of flexible semi-permanent materials, can also be used in a double line, parallel to the banks, to facilitate settling of silt and growth of vegetation;

iv. construction of temporary or permanent structures in sections where the gradient is steep, to facilitate siltation and thereby stabilize the grades. Fig. 13 illustrates some control measures.

Certain plants are suited to torrent control schemes, particularly the outsprouting types which grow profusely near stream beds, e.g. *Salix* species, *Vitex nugundo*, *Populus* species, *Arundo* donax, *Ipomea cornea*, *Jatropha curcas*, *Pennisetum purpureum* (Napier) etc. A series of checkdams made of tree logs, buttressed by permanent checkdams at wide spacing, can be used to control torrents rushing down steep slopes. The torrent banks can be protected by planting water-loving vegetation (Singh et al, 1974; Tejwani et al, 1975).

Fig. 13 Torrent control by rivetments, with shell structures supplemented by contour planting of Salix in the Ramganga catchment of the northern Himalayan region.

7.2 Stream Channel Erosion

In the Indo-Gangetic alluvial and Assam Valley regions, the problem of stream erosion is serious; a classic example is the age-old case of the flooding and shifting course of the river Kosi. In the process of building up inland deltas, the Kosi has shifted over 167 km from east to west during the period from 1738 to 1964 (Anon, 1971b). The cause of this shift has been attributed to the enormous load of sand which the river is unable to transport and unloads into the main drainage channel. In 1941, Mr. C.C. Inglis, Director of the Central Irrigation and Hydrodynamic Research Station, identified the build up of the sub-mountainous delta, by the excess charge of sand brought from the hills, as the main cause of this shift. In subsequent years, attempts were made to confine the river course by constructing embankments. It has been observed that though the river is being kept confined within the flood embankments, its nature of shifting its course has not changed at all. Formation of new 'chos' is going on within the embankments and the river configuration changes every year after the floods (Anon, 1976d). The same story applies to stream bank erosion due to the heavy sediment load of the rivers draining into the Assam Valley.

The National Commission on Agriculture has also recorded the problem of riverine lands. Heavy sediment loads carried by rivers through steep slopes result in meandering and serious bank erosion; this is especially so with rivers originating in the Himalayas. The Teesta in the north-eastern Himalayan region, carries possibly the world's largest sediment load of about 98.20 ha m/100 km^2/yr (Gupta, 1975). In the Indo-Gangetic alluvial and Assam Valley region, fertile areas with flourishing crops, orchards, towns and cities are often destroyed.

These lands are known by various names in different parts of India, such as, 'khadar' in northern India, 'diara' in central India and 'ghar' in eastern India. The estimated riverine land is about 2.4 million ha in the Indo-Gangetic alluvial region alone. Such problem lands also exist along the 8-10 km wide stream bed of the Sutlej which was confined by raising embankments during 1962-65, as well as in the wide bed of the Beas. Such lands, commonly known as 'rao', are also sizable in a number of bigger torrents. In order to utilize these wastelands profitably, the first necessity is to provide adequate protection from flooding during the high flow years. After this, soil conservation treatments could be applied to improve conditions gradually for better land use management. There has not been much concerted activity in this respect yet.

7.3 Torrent and Stream Erosion in relation to Flood Control

The problem of 'chos', stream erosion and riverine lands needs to be viewed in conjunction with the problem of floods. From Fig. 2, it will be clear that the regions subject to regular flood havoc are the Indo-Gangetic alluvial, Assam Valley and Gangetic delta. The damage done is largely due to the sediment brought down, from the hills. It is, therefore, necessary that the plan for controlling 'chos' and other stream erosion should form an integral component of flood control programmes. The current attempts to control floods by protection structures downstream need to be supplemented by long-term catchment treatment measures. The expensive flood control structures on the Kosi river have not yet been successful in preventing shifting of the river course and formation of deltas which now threaten the very protection embankments (Anon, 1976d).

Banerjee and Lal (1972) reviewed the problems of flood and sedimentation of four major river systems, i.e. north-western rivers, Ganga, Brahamputra and the peninsular rivers. Considering the amount spent on flood protection and the flood damage over the years, it can be observed that, while flood protection activity increases, losses due to floods paradoxically also increase. Such is the case even in a developed country like the USA. It also clearly shows that structures downstream alone are not sufficient for the conditions obtaining. While acknowledging the important role of structural means, Banerjee and Lal (1972) said that the following measures should also be taken: i) improvement of the capacity of channels to carry floods end improvement of drainage generally; ii) raising of low lying villages, and iii) soil conservation work in catchments.

There is a school which shares the view that high floods cannot be controlled or moderated by catchment treatment as the coincidence of the factors causing floods are beyond human control. There is no denying the fact that wrong land use, e.g., large-scale felling of trees or excessive grazing at higher altitudes, and unscientific cultivation of hill slopes, contributes huge amounts of silt from the watershed. Afforestation on steep slopes and conversion of steep cultivated lands into benches in the Nilgiris (Region 9, Fig. 4) have, however, increased the annual basin retention capacity of the catchment by about 28 cm (Raghunath et al, 1970; Das et al, 1975). In the northern Himalayan region, at Chandigarh, runoff from degraded watershed was reduced by 54.2% by treatment with earthen debris basins, pondage banks, staggered contour trenches and afforestation (Patnaik et al, from Anon. 1974). Another package of conservation measures in a watershed reduced the sediment production rate from 80 t/ha/year over a decade (Bhumbla, 1976). At Dehra Dun in the same region, replacement of scrub forest by Eucalyptus resulted in a 30 and 77% reduction in water yield and peak respectively, while narrow base terracing (contour bunding) reduced runoff peak by 40% (Mathur et al, and Ram Baby et al, from Anon. 1974).

All this demonstrates that the saturation of watersheds requires a far greater input of conservation measures, including small hydrologic structures if peak floods are to be moderated, even when they are large scale. Therefore, it may be said that by treatment in catchments, floods due to a 100 years' rainfall event could possibly be moderated to the scale of 70 or 50 years. But there are no data available to prove or disprove this.

8. LANDSLIDES AND ROADSIDE EROSION

8.1 Landslides

Landslides and slips are a serious problem occurring extensively in the north-eastern and northern Himalayan region. They generally represent a downward mass movement of earth and boulders and include soil creep, flowslides and land slips. Landslides cause disruption of communication lines and transport, dislocation of public utilities, loss of land and buildings, siltation of reservoirs, etc. and loss of life.

Geology coupled with high rainfall is the primary cause of Indian land slides. There are many causes but two common physical ones are: instability of slope and inadequacy of drainage in the sliding mass. However, the degree of hazard is accelerated through deforestation, overgrazing and other human activities, e.g. road building and mining materials from hill slopes. The various types of land slides and their causes have been briefly described by Tejwani et al, (1975).

8.1.1 Treatment

A catchment-based operational project at Dehra Dun in the northern Himalayan region showed that land slides need to be controlled on the basis of a well defined watershed, and treatment to the sloping areas as well as water courses needs to be provided in stages. Protecting the watershed against biotic damage by a closure is often a necessity. To prevent toe cutting along the water course, retaining walls are constructed. To facilitate the growth of vegetation, slopes are broken by contour wattling, preferably with plant species that can be vegetatively propagated. These temporary supports coupled with protection against biotic interference provide conditions conducive to a natural succession. The steeper slopes are broken by stone retaining walls. In some of the sliding faces, where moisture becomes critical in the post-monsoon season, the straw mulching tied with thin wires helps in the establishment of vegetation. Besides stabilizing the earth faces, it is essential to stabilize the small as well as big water courses in the watershed. The erosive gradients of the main water courses are rectified by a series of checkdams and their banks are protected from scouring by building jetties and spurs. Small ones are treated with a series of log or crib checkdams or checks of live material, e.g. Napier, at close intervals (Fig. 14).

8.1.2 Selection and establishment of vegetation

Plant species should be selected which have a deep root system that will penetrate and bind the profiles together. Vegetation with shallow roots which is good for cover protection e.g. 'Kudzu' (*Pueraria hirsuta*), is not suitable in such sites. Futhermore, 'Kudzu' is aggressive and smothers other types of vegetation which require some years to establish themselves. When planting Napier or other vegetation that can be vegetatively propagated, it is more effective to plant it slanting, thereby ensuring greater sprouting for better anchoring on the soil mass.

Fig. 14 Stabilizing torrents on hill slopes subject to landslides by a series of log and wire-crated (gabion) checkdams, mulching and afforestation at Debra Dun, northern Himalayan region

8.1.3 Structure types and selection

Regarding the material for check dams, spurs, etc., a lot of experience has been gained. Field observations of the rigid structures, including RCC ones constructed along hill roads, have shown that often they do not perform satisfactorily, mainly due to seepage of water that generates heavy pressure and ultimately causes their failure. Also in the case of checkdams along the main water course, site conditions may be poor and a proper foundation is difficult to achieve; in such locations rigid structures do not succeed either. In addition, the accumulated sediment behind the checkdams permits large scale seepage and the removal of the seepage water from behind the checkdam is an absolute necessity. Flexible structures, e.g. wire-crated checkdams or retaining walls, or checkdams made of gabions endure better. They can take differential sinking, stand localized bulging due to pressure of debris or water and permit the escape of accumulated water from behind the structure. Furthermore, if a gabion is broken or damaged, it can be repaired without reconstruction of the entire structure. The gabions and such structures are made on site by semi-skilled labourers themselves (Gupta and Dalal, 1967). These structures are also becoming popular along mountain roads and are commonly known as 'sausage' structure (Fig. 15). For smaller water courses, checkdams made of wooden logs or loose stones or slabs can also achieve the same results.

Fig. 15 Stabilizing steep hill slopes with series of 'sausage' wire-crated boulder retaining walls in the Teesta catchment (Sikkim) in the north-eastern Himalayan region

In the entire concept of treating land slides or slips the key factors are: i) treating the catchment area and the water courses together; ii) using vegetation and engineering structres in combination; and iii) preferring flexible structures to rigid structures and a system of small ones to a single large one.

8.2 Roadside Erosion

Erosion along the road or railway lines is a regular phenomenon as the alignments cut across the natural physiography and thus disturb the balance (Fig. 16). The stabilization of a road or railway embankment takes some years and with the construction of extensive road systems in the plains as well as in mountainous areas, the problem has become more acute. In the northern and eastern Himalayan region, erosion along the cut and filled faces of roads is extensive. The inadequacy of cross drainage structures often results in defective drainage of water and as a result roadside gullies are formed, which not only threaten the stability of the roads but also set in motion the chain of severe erosion in adjoining good cultivated lands, which ultimately necessitates expensive remedial treatment (Fig. 17).

Erosion along railway lines is also considerable. It differs from place to place depending upon the amount of rainfall and type of soil. Common measures to check such erosion are turfing, pitching, retaining walls and even terracing the slopes of the fill section. To check erosion by meandering rivers which threaten the railway lines, protection is provided in the form of guide bunds with pitched slopes, toe guards of 'sausage' structure or concrete blocks, spurs and revetments. Among the local items, bamboo screens, bamboo bundles and triangular permeable screens of bamboo are used with great success. To prevent erosion along cut faces catch-water drains, deep boulder drains, cross bunds, etc. are used (Palit and Kapoor, 1975).

Fig. 16 Roadside gully erosion in the Mayurakshi catchment, eastern red soil region

Fig. 17 Gullying along the road due to inadequate cross-drainage and stabilization, e.g. closuring, drop structures, earth bunds, afforestation, in the Mayurakshi catchment, eastern red soil region

9. EROSION DUE TO SHIFTING CULTIVATION

Shifting cultivation or 'jhuming' is practised mainly in the north eastern Himalayan region and marginally on other non-Himalayan hills (Fig. 5). The practice, evolved over centuries, incorporates a mixed land use pattern appropriate to the physiographic remoteness and lack of communication. This remoteness has forced the people to adopt a system that is self-contained and involves the minimum number of items. The problem of 'jhuming' has engaged the attention of various agencies for quite a few decades; the National Commission on Agriculture (1976c) cites about 19 references and though these reports differ on many points, there is agreement that improvement in land use management in the areas subject to this practice is urgently needed. The latest estimate by Miss Wadia (1975) indicates that about 2.7 million ha are affected by shifting cultivation in the north-eastern Himalayan region alone (including non-Himalayan hill ranges) and the average area cultivated by a family is 0.92 ha.

To meet the exigencies of collective security and to adjust individual needs and responsibilities vis-à-vis community ones, the system seems to have served the people of the area remarkably well. The question does arise as to why it has become urgent to review the effectiveness of this system, which has not only evolved in India under certain conditions, but also in many parts of the world with similar conditions.

9.1 Degradation Hazards

Opinions differ on the associated hazards of soil degradation and consequent sediment and flood havoc caused by the practice of 'jhuming' on hill slopes. Some people hold the view that shifting cultivation, which does not involve ploughing and other intensive agricultural operations, does not disturb the soil greatly. It is true that there are no systematic studies available to illustrate the sediment hazards from the areas subject to shifting cultivation. In the past when the 'jhuming' cycle was long, about 20-30 years, it is possible that there was no appreciable degradation of land or ecology; but the cycle has now become as short as 1-3 years which does not permit any natural recuperation by the land. However, from Table 2 it can be seen that the area receives between 1 500 - 2 500 mm of rainfall and the slopes are, by and large, steep. The area is also subject to heavy landslides, accelerated by an intensive road development programme. Floods with a heavy silt load create havoc almost annually in the Assam Valley.

To set aside any doubts, data from the Machkund catchment (No. 6 in Fig. 18) can be cited; it is close to the eastern coast and covers slopes in the eastern Ghat. The entire area is populated by tribes who have practised shifting cultivation (locally called 'podu') for centuries. Since the Centrally Sponsored Scheme for Soil Conservation was launched in the Machkund catchment during the Third Five Year Plan, about 40% of the critically eroded areas have been treated up to 1975-76, and as a result, the siltation has fallen from 3.38 to 2.51 ha m/100 km^2/yr (Table 3). In addition, it can be concluded from field observation that areas subject to shifting cultivation become depleted of better flora and fauna over the succeeding cycles.

9.2 Treatment

To tackle this problem, Dhebar's Commission (cited from Anon, 1976c), suggested that a coordinated approach be taken to provide employment opportunities in forestry, agriculture, animal husbandry and industry for at least 300 days in a year. This needs to be examined within the background of multiplicity of vocations and the rising aspirations of the people of the area to adopt better vocations and a higher standard of living with the opening of the area by a

Table 3 SEDIMENT PRODUCTION RATES VIS-A-VIS SOIL CONSERVATION WORKS IN A FEW SELECTED RIVER VALLEY PROJECT CATCHMENTS

No. Reservoir Catchment		Catchment area 1 000 ha	Sediment Production Rate ha m/100 km^2/yr		
			Assumed	Original (Year)	Reduced (Year)
		56 87 000 Total			
1.	Bhakra	37 160 (within India)	4.28	8.38	6.14
2.	Maithon DVC	521	1.62	15.45	13.10
3.	Panchet DVC	981	2.47	13.32	10.30
4.	Machkund	195	3.57	3.38	2.51

modern communication system and the introduction of currency. Therefore, it must be carefully considered whether the same family, who may want to send some if its members for education and other vocations, will be in a position to cultivate or manage larger areas with the labour available without substantial support from improved inputs, such as irrigation, fertilizer, better seeds and appropriate tools, implements and machinery. This integrated development is being tried on a pilot scale in the north eastern Himalayan region where a family is being provided with a hectare of irrigated land and another hectare of dry land with additional support for raising profitable forest, horticulture or other plantation crops. To improve the ability of families to manage these enhanced areas, demonstrations are being given on the use of appropriate tools, implements and machinery. Considering the level of present development, big tractors or equipment cannot be introduced in these areas to bring about an agricultural revolution within a short time: the process has to be gradual and in stages. To begin with, the large number of indigenous tools should be studied and, if found suitable, their designs improved. The storage bin, similar to that which has proved useful in the Punjab, winnowing and threshing machines may be of immediate use.

Unless the 'jhumias' or shifting cultivators can be weaned from the practice by a profitable alternative vocation suiting their socio-cultural background, the problem cannot be solved. And if this goal cannot be achieved, the direct objective of reducing erosion and consequent sedimentation accompanied by heavy floods cannot be fulfilled either.

10. SOIL CONSERVATION IN THE CATCHMENT OF RIVER VALLEY PROJECTS

India has been building up her irrigation and hydro-electric potential steadily over the years. These projects are mostly multipurpose. The sites of the reservoirs are the gift of nature and therefore not profuse in numbers. The projects provide water for irrigating the downstream areas and thereby increase agricultural production. The stored water is also used to generate electricity for developing industries and intensifying agriculture. It is, therefore, essential that the reservoir capacity created should be preserved as long as possible. Even though allowance has been made for unavoidable sediment flowing with the water, the rate of sedimentation in most of the reservoirs has been very high;

a few of examples can be seen in Table 3. The sediment production rates of some of the multipurpose reservoirs at present range from 2.5 to 18 ha m/100 km^2/yr (Gupta, 1975); he also draws attention to the higher silt load of Himalayan rivers than non-Himalayan ones.

10.1 Effect of Sedimentation

The accelerated sedimentation of the reservoirs has, in many cases, already affected the irrigation potential created. For example, in Nizamsagar reservoir the present capacity of the reservoir is 338 million m^3, against the initial 898 million m^3. With this loss of capacity, there is not enough water available to irrigate the designed command area of 110 000 ha for growing sugarcane and paddy. The lack of supply of sugarcane has already threatened the functioning of sugar factories including that of the Bodhan Sugar Factory, the largest in south east Asia (Suba Rao, 1974). Furthermore, sediment coming from the catchment is degrading it at a fast rate, thus reducing the all-round productivity.

10.2 Watershed Approach

The problem of preserving the reservoirs is combined with improving productivity in the catchment area and preserving the existing productivity of the command area. Realizing a complex nature of the problem, a scheme was launched during the Third Five Year Plan to treat a few of the catchments in the river valley projects. To date, this scheme is operating in 30 such catchments (Fig. 18), which cover an area of about 79 ha each and almost all types of erosion and conservation problems are present in these catchments. Because of obvious financial constraints and lack of technical personnel, it is impossible to treat all areas immediately and, indeed, it may not be necessary to treat all of them to prevent considerable sedimentation of the reservoirs and degradation of the catchment. A priority survey is being conducted by the All-India Soil and Land Use Survey of the Government of India to ascertain the critical areas of degradation in these catchments. The methodology developed takes into consideration the erodibility of soils, topography, vegetation, channel system, status of erosion, erosiveness of the climate as well as the proximity of the watershed to the reservoir or main tributaries draining into the reservoir (Bali and Karale, 1973). From the area surveyed so far in various catchments, it appears that about 15% of the land can be considered as highly critical and should be treated immediately. Such areas are being identified as small watersheds having a national treatable area ranging from 2 000 to 4 000 ha.

The macro plans are drawn up first on the basis of sub-catchment/sub-basins and then more detailed micro plans are prepared for small watersheds or sub-watersheds within the sub-catchment/sub-basin, although, the actual implementation of works should proceed from the micro level, i.e. on the basis of watershed/sub-watersheds. This helps utilize the available resources to the maximum, and accommodates inevitable changes occurring while planning details or even while implementing the plan.

10.3 Implementation of the Programme

During the Fifth Plan, about 240 such watersheds are receiving saturation treatment, i.e. remedial measures for all types of land and associated drainage systems. The measures for treating agricultural land comprise bunding, bench terracing and grassed waterways and sometimes ponds, non-agricultural lands are provided with closures for restricting grazing, afforestation and grassland development. Gullies and stream bank erosion are treated with structures, periphery bunds and vegetative measures. In extremely degraded land, contour dyking and ditching is done to improve soil and moisture conservation, also enclosures are built for regeneration of grass and shrubs. Sediment trap basins

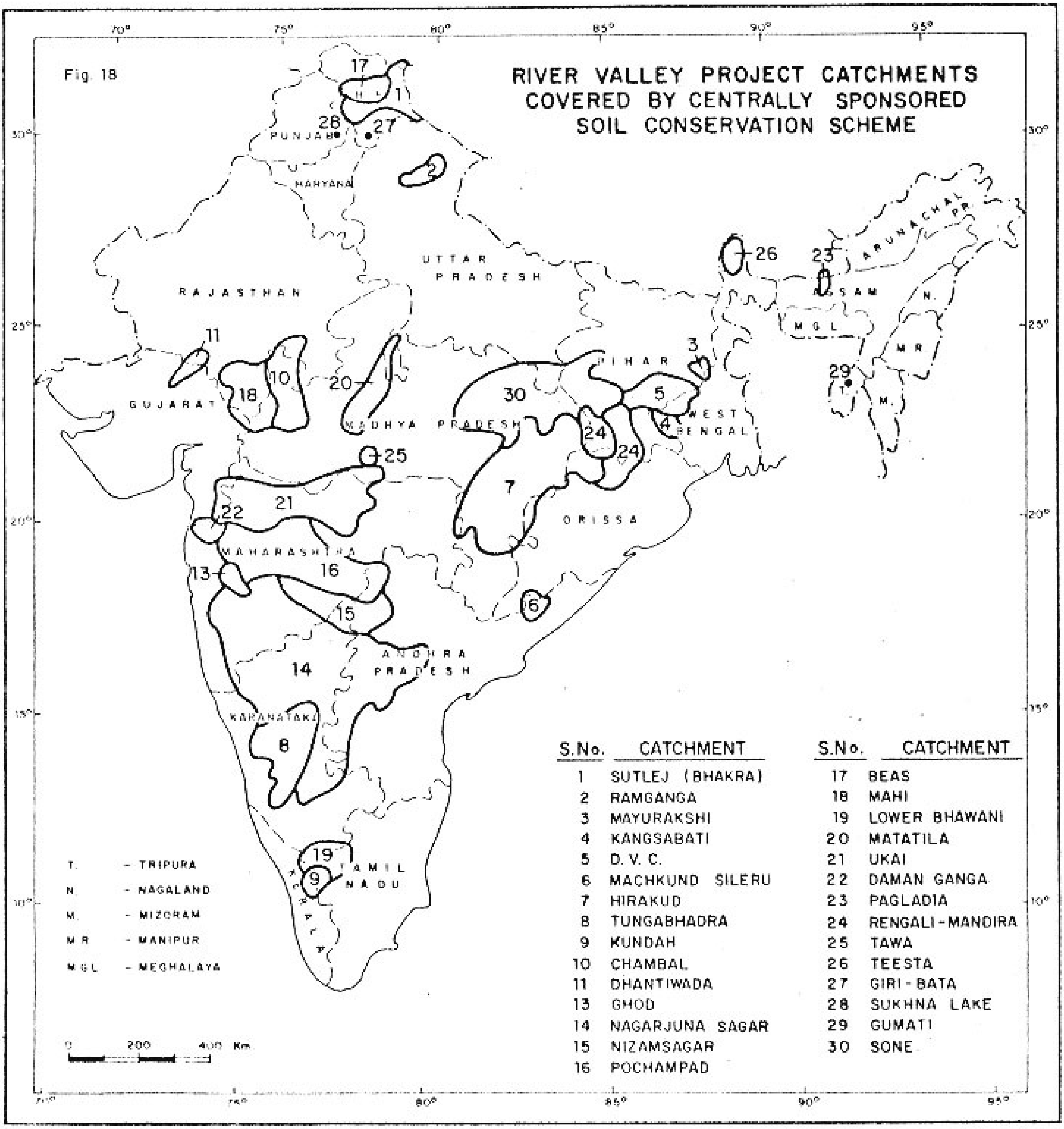
Fig. 18
RIVER VALLEY PROJECT CATCHMENTS
COVERED BY CENTRALLY SPONSORED
SOIL CONSERVATION SCHEME
PUNJAB
HARYANA
RAJASTHAN
UTTAR PRADESH
GUJARAT
MADHYA PRADESH
BIHAR
WEST BENGAL
ORISSA
MAHARASHTRA
ANDHRA PRADESH
KARANATAKA
TAMIL NADU
KERALA
ARUNACHAL PR.
ASSAM
MGL
N.
MR
M.
T.
T. - TRIPURA
N. - NAGALAND
M. - MIZORAM
MR - MANIPUR
MGL - MEGHALAYA
0 200 400 Km
S.No. CATCHMENT
1 SUTLEJ (BHAKRA)
2 RAMGANGA
3 MAYURAKSHI
4 KANGSABATI
5 D. V. C.
6 MACHKUND SILERU
7 HIRAKUD
8 TUNGABHADRA
9 KUNDAH
10 CHAMBAL
11 DHANTIWADA
13 GHOD
14 NAGARJUNA SAGAR
15 NIZAMSAGAR
16 POCHAMPAD
S.No. CATCHMENT
17 BEAS
18 MAHI
19 LOWER BHAWANI
20 MATATILA
21 UKAI
22 DAMAN GANGA
23 PAGLADIA
24 RENGALI-MANDIRA
25 TAWA
26 TEESTA
27 GIRI-BATA
28 SUKHNA LAKE
29 GUMATI
30 SONE

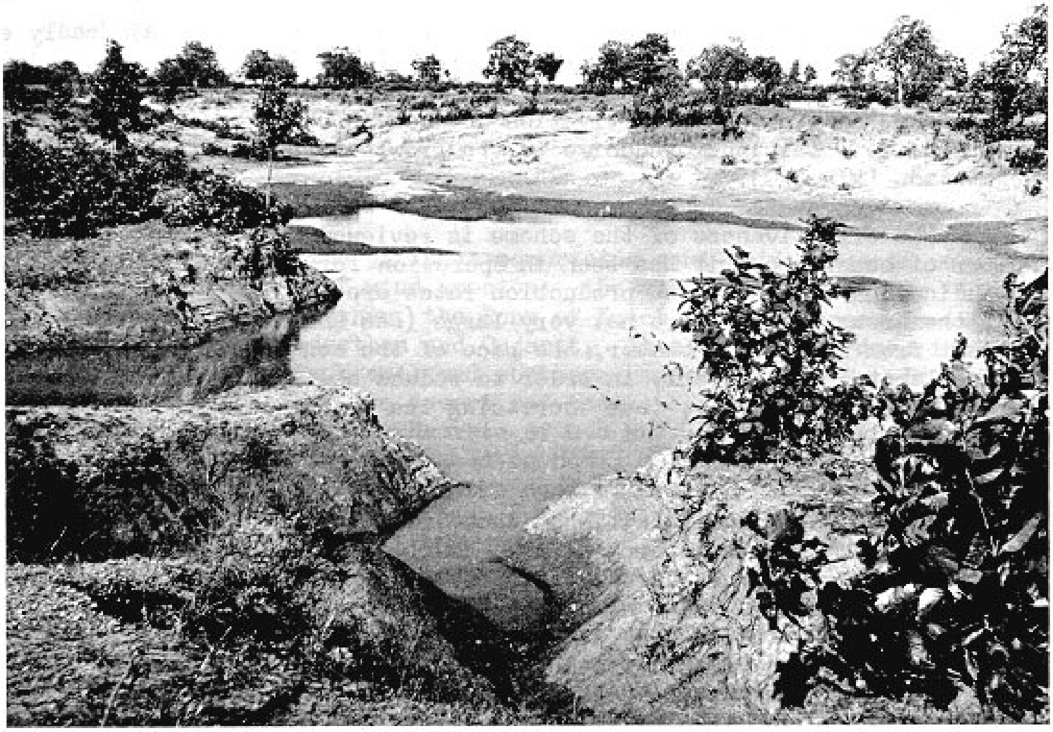

Fig. 19 Sediment detention tanks in a watershed of the Damodar Valley Corporation, eastern red soil region

Fig. 20 Good vegetation restores the eroded landscape owing to better soil and moisture conditions created by sediment detention tanks - Damodar Valley Corporation, eastern red soil region

on upstream watersheds are constructed to hold sediment, reclaim badly eroded land and improve the all round moisture condition (Fig. 19); they also moderate floods and recharge groundwater (Bhumbla, 1976). These small ponds help in reclaiming downstream land for paddy cultivation and can be used for irrigation too; they also provide conditions conducive to the growth of better trees and other vegetation (Fig. 20).

The effectiveness of the scheme is reviewed from time to time and in a number of cases where it has been in operation for a considerable time there is an indication that sediment production rates are falling in spite of the fact that the areas treated were not very large (Das and Kaul, 1976); this is also evident from Table 3. However, the pace of the conservation programme needs to be accelerated considerably in order to reduce sedimentation rates below the permissible ones quickly, thus increasing the useful life of the reservoirs.

10.4 Catchment Area Authority

It has been well established that, whatever the type of erosion or conservation hazard, the source area as well as the affected problem area must be treated together. Thus, irrespective of the type of erosion, the planning and implementation has to be on the basis of a natural unit, i.e. a watershed or catchment. The solution does not only cover protection and stabilization, but also its continuing effectiveness through appropriate maintenance and follow-up practices. This is possible when the beneficiaries are involved intimately in managing the treated land by a judicious land use plan which gives sizable direct and indirect benefits (Bhumbla, 1976).

Considering this vital need, catchment area development authorities are being constituted for different catchments in different States embarking on developmental activities in an integrated manner on a catchment basis.

11. COASTAL EROSION

India has a coastline of 5 700 km, along the east and west (Singh, 1971) where sea and wind erosion cause problems in certain places, especially during the monsoon. The various stretches subject to erosion are shown in Fig. 5. The problem is acute in the north of the east coast and the southern portion of the west. Littoral drift at about 1 million tonnes has been observed to be north-east during the south-west monsoon, and south-west during the north-east monsoon at about 0.25 million tonnes; this leaves a net northern drift of 0.75 million tonnes/year. This information relates to Pondicherry only (Deivasingamany, 1975). The area affected is roughly between 50 and 80 thousand km^2 (Anon, 1976b).

11.1 Treatment

About 50 years ago, French engineers, for the first time, built a vertical coastal wall to safeguard the territory in Pondicherry, but even two decades ago, the sea in Pondicherry was about 400 m from its present position. Over the years, the following measures have been taken to check the problem of sea and wind erosion along the coast:

1. creation of protective sea walls whereever essential;

2. plantations of casuarina on the sandy foreshores, buttressed by inland plantations of cashewnut, eucalyptus and coconut.

The National Commission on Agriculture (1976) recommended a similar technique.

In certain pockets along the west coast, fertile lands are inundated by sea water; special attention should be paid to the prevention of salt water incursion through appropriates drainage and proper follow-up and maintenance works to enable the growing of profitable crops. A composite treatment for these lands has yet to be evolved.

12. WIND EROSION

A very sizable portion of India comprising semi-arid and arid regions is subject to varying degrees of wind erosion; the area is shown in Fig. 5 and it includes the desert of Rajasthan, the Runn of Kutch, coastal areas in the south and contiguous areas of Rajasthan and Gujarat. It also extends deep into the Indo-Gangetic alluvial, black soil and southern red soil regions. In the early 1950s, it was estimated that the desert had been encroaching upon adjoining lands in Uttar Pradesh and Haryana at the rate of 0.8 km/year and that for the last 50 years the encroachment was estimated to be 13 000 ha. There may be differences of opinion regarding the marching of the desert, but the damage done by blowing sand-laden winds to the adjoining lands cannot be ignored. The great Indian desert in reality does not fulfil the usual idea of a desert - a great stretch of sand, a tract entirely devoid of streams with few rocks and a large number of sand hills. The Indian desert contains a substantial number of flora; its population, though thin compared to many parts of India, is considerable and it has large herds of camel, sheep, goats, etc. (Blanford cited from Misra 1967). The air over this region contains a quantity of precipitable moisture comparable with that of many other locations in the country with a less severe environment. It could therefore, be said that, apart from the continuous interaction of meteorological, geological and hydrological changes over the centuries, for which evidence is available, the desert condition has definitely been accentuated by the activities of man. The arid land of Gujarat, particularly the Runn of Kutch, on the other hand, has the twin problems of excess salt and an acute shortage of fresh water.

The dispersion ratio for desert soils ranges from 33 to 83 and that for Kutch is 65 (Table 2), which indicates their high erodibility.

12.1 Approach to the problem

Considering the inherent limitation of precipitation and high temperature, it may not be possible to develop the greater part of the region to the extent that it can provide a sizable area of intensive agriculture, in spite of the fact that the Rajasthan Canal scheme is bringing a total change in environment to a portion of the desert. For the rest of the area, in the future, the solution needs to be based on principles applied to arid zone development. Any programme planning should take the following into consideration:

i. resources in the great Indian desert area must be managed under arid and semi-arid condition and not under the extreme limitation of desert conditions;

ii. a livestock-cum-agricultural economy prevailed in the region for ages and still, in spite of the advancement of technology, will hold the key for any sustained solution; therefore, grassland or pasture development will play a very important role;

iii. the delicate environmental balance needs to be restored and ways and means found to prevent frequent disturbance of this delicate balance.

12.2 Treatment

An integrated desert development technology is being developed by the Central Arid Zone Research Institute at Jodhpur to tackle the problem. The main thrust is on stabilization of sand dunes, afforestation, raising of wind breaks and shelterbelts, and contour bunds and stubble mulch farming. Work on development of water harvesting techniques is also in progress. Among the plants becoming effective in the Rajasthan desert and adjoining areas are *Acacia tortilis* (Kaul, 1970), *Eucaluptus* species, *Acacia nilotica*, *Dalbergia sissoo* and grasses like *Cenchrus ciliaris*, C. *setigerus* *Lasiurus sindicus* and *Dichanthium annulatum* (Bhimaya *et al*, 1968).

The technique of stabilizing shifting sand dunes by afforestation consists of: (i) protection against biotic interference, (ii) treatment of sand dunes by fixing materials in parallel strips or chess board design using local shrub materials and starting from the crest down to the heel of the dune to protect seedlings from exposure or burial, and (iii) afforestation of such treated dunes by direct seeding and planting (Kaul, 1970).

Along the coast in the southern red soil region, there are the problems of coastal sand dunes and considerable wind erosion. Here, sand dune fixation and provision of wind breaks are the common practices. The species usually used are *Prosopis juliflora*, *Azadirachta melia*, *Acacia nilotica*, *Casuarina equisetifolia*, *Jatropha* species, etc. (Sivasundaram, 1967).

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Paper No. 2 TRADITIONAL FORMS OF LAND USE IN RELATION TO SOIL EROSION

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1. INTRODUCTION

Many of the relationships between traditional land use and soil erosion are, as generalizations, widely known. There can be few students who, on being required to write upon the topic, would not instantly produce the statement that methods of shifting cultivation, if continued unchanged under increasing population pressure, will lead to soil degradation and ultimately erosion; or that pastoral nomadism, with grazing land communally owned, is nowadays almost invariably accompanied by vegetation degeneration and often also erosion. Equally well recognized is the role of insecure tenancy in removing the incentive for soil improvement and conservation. Yet these statements, whilst they may be over-generalized, are nonetheless very true and indeed are some of the most important things that can be said upon the subject.

In contrast with generalizations, case studies are comparatively few and mostly descriptive. Many contain accounts, maps and often spectacular photographs of the nature of the erosion. Only few include measurements of its rate on actual farmed lands, as opposed to experimental plots (Rapp et al, 1972, is a noteworthy exception). But few go into depth about the technological, economic and institutional conditions that have led to the onset and continuance of the erosion. In part, the gap between natural and social scientists may be held responsible for this deficiency, in part the political sensitivity of studies of such a type.

So in approaching this review, one encounters on the one hand, a body of received truths, over-generalized but fundamentally correct; and on the other, a lack of case studies which encompass the whole range of the problem —— for it is indeed broad, starting from the technical aspects of erosion resistance, extending through land management practices and economics, and reaching into questions of land tenure and ultimately politics.

Two terms in the title call for interpretation. Under "traditional" I include not only long-established practices that continue relatively unaltered but also the modifications of them brought about by population pressure and other modern changes. "Land use" is taken to include both technology, e.g. cropping systems, and social or institutional aspects, notably land tenure. To do otherwise would be neither realistic in the former case nor useful in the latter. Two common forms of land tenure in the developing world are excluded as not traditional: plantations and state farms. Forms of collective land ownership found in socialist countries are, however, included, for they are a modern adaptation of traditional land use and some explicitly incorporate features of early types of communal responsibility.

2. TRADITIONAL LAND USE

Types of land use can be classified by a wide range of criteria; these are listed, for example, in the methods for description of a land utilization type as set out in the FAO Framework for land evaluation (FAO, 1976) and in the International Geographical Union Typology of world agriculture (Kostrowicki, 1974). Given the restriction to traditional uses in developing countries, certain features are common to all or most of the types: small farms (or, in communal holdings, low land per capita), low incomes, a low degree of mechanization and, often, of commercialization.

Two criteria are of greatest importance in relation to soil erosion: technology of use, and land tenure. Under technology of use are included types of crops or other produce together with land use intensity; under land tenure, all traditional and legal institutions which control rights to the use of land, the provision of inputs to it, and the benefits from its production. Tables 1 and 2 show uses classified separately by these two criteria.

In the classification by technology (Table 1), annual cropping includes both cereal and root-based systems, usually the former in the savannas and the latter in the forest zone. These are subdivided according to intensity of cultivation, using the limiting values of Ruthenburg (1971). Semi-permanent and permanent cultivation systems may include supplementary livestock; a class of mixed crop-livestock farming is included to cover systems in which livestock is an essential component, e.g. smallholder dairying in upland Kenya. Since plantations are by definition excluded, perennial cropping refers to cultivation of perennials by smallholders, usually in association with subsistence crops (e.g. oil palm/cocoa with yams/sorghum/plantains in West Africa, rubber with rice in Malaysia). Systems dominated by swamp rice cultivation are for convenience grouped under irrigated agriculture: a further class of smallholder irrigation covers areas such as the mixed cropping based on wheat in the Punjab. Both classes of irrigated agriculture contain, however, their own mechanisms for prevention of erosion and will not be further considered. Pastoralism is divided into the "most traditional" form of total nomadism, and the nowadays more common semi-nomadism in which at least part of the family remains static for part of the year and there is supplementary cultivation. Where pastoralism becomes fully sedentary, and cultivation an essential component, we reach by a different route the mixed crop-livestock farming listed under annual cropping. Pastoralism could be further subdivided according to intensity of stocking, as hectares per livestock unit.

In relation to later discussion of erosion, it is relevant to make some comments on how the actual situation today differs from the stereotypes of older textbooks. First, shifting cultivation is fast giving place to semi-permanent and permanent cultivation. This change took place long ago in the Deccan of India and has occurred in this century in many parts of Africa. I believe that much of the 36 million square kilometres of land recently listed as under shifting cultivation (FAO, 1974, pp. iii,1) has an R factor over 30 percent, and no small part is under quasi-permanent cultivation. I now teach students that the "normal" form of agriculture in the savanna zone is permanent annual cropping, and that in many countries shifting cultivation is a rare survival, deserving to be listed as a tourist curiosity! A second comment is that the "textbook" view that cultivating peoples do not own cattle, and vice versa, is wrong; not only in India but commonly in Africa the cultivators, or at least the slightly better off among them, possess cattle, often herded communally. Thirdly, a state of semi-nomadism to sedentary crop-livestock farming is steadily replacing (if not without opposition!) the 'wandering nomad'; the Fulani of West Africa provide examples of all steps in the transition.

Table 2 shows traditional land use classified by form of land tenure. The primary division is into private ownership, tenancy and communal ownership (plus the "non traditional" state ownership). The main form of private ownership is the family farm (also called owner-occupier and peasant smallholder). The *latifundia*, or large estate worked by tenants, is characteristic of Latin America and so given its Spanish name: it is "traditional" by virtue of four centuries' standing. Tenancy is divided according to whether landlords receive a fixed cash rent, a period of labour (as commonly on *latifundia*) or a share of the crop. Under communal ownership, common land refers to land which may be nominally held by the state but which in practice is open to a wide range of users and the responsibility of none. Village ownership refers to the system often found in Africa in which ownership is vested in the chief, headman or village council, and this authority allocates rights of use to individuals. Collective ownership refers to village-based systems involving communal working of the land, which are the standard form of tenure in communist countries and occasionally found, as owner-cooperatives, elsewhere.

Table 1. <u>CLASSIFICATION OF LAND USE IN DEVELOPING COUNTRIES BY TECHNOLOGY OF USE</u>

Non-traditional types in brackets. R = years cultivated /years in the cultivation-fallow cycle, expressed as a percentage (Ruthenburg, 1971)

ANNUAL CROPPING	SHIFTING CULTIVATION	R <30
	SEMI-PERMANENT CULTIVATION	R 30-70
	PERMANENT CULTIVATION	R >70
	MIXED CROP-LIVESTOCK FARMING	
PERENNIAL CROPPING	ASSOCIATED WITH SUBSISTENCE CROPS	
	(COMMERCIAL MONOCULTURE)	
IRRIGATED AGRICULTURE	SWAMP RICE CULTIVATION	
	OTHER SMALLHOLDER IRRIGATION	
PASTORALISM	NOMADISM	
	SEMI-NOMADISM	
	(RANCHING)	

Table 2. <u>Classification of land tenure in developing countries</u>
Non-traditional types in brackets.

PRIVATE OWNERSHIP	FAMILY FARM
	LATIFUNDIA (ESTATE)
	(PLANTATION)
TENANCY	CASH RENT
	LABOUR TENANCY
	SHARE CROPPING
COMMUNAL OWNERSHIP	COMMON LAND
	VILLAGE LAND
	COLLECTIVE
(STATE OWNERSHIP)	(STATE FARM)

Many of the stereotypes, such as the indebted share-cropper or the insecure tenant, are regrettably still true, notwithstanding efforts of governments to change them. Two comments on the standard picture may, however, be made. First, it is widely found that the village ownership system is giving place to a situation approaching freehold, the change being associated with the transition from shifting to permanent cultivation. The "right to cultivate" nowadays often covers the same plot of land throughout a lifetime, and is retained on transfers through marriage and inheritance. There is de facto security of tenure, the main difference from freehold being absence of the right to sell land. Secondly, the frequent association of this same system with grazing land held and used communally by the village may be noted, for it has important consequences for erosion.

The number of combinations of technology and tenure is considerably less than the theoretical 72 possible by combining Tables 1 and 2, since many types of technology are linked with systems of tenure. Moreover, where areas as a whole are being considered, as opposed to individual farms, private ownership is nearly always mixed with tenancy. Some examples of combinations are given in the discussion of erosion below.

3. RELEVANT ASPECTS OF SOIL EROSION

As a basis for relating erosion to land use, it can be noted first, that erosion is frequently preceded by degradation, of soil, vegetation or both; secondly, that erosion may be continuous, causing damage over a period of years (often sheet erosion), or catastrophic (often gullying); and thirdly, that we are concerned both with the prevention of erosion and with remedial measures where it has already occurred. Given this basis, some aspects which should be taken into account when studying a given land use system in relation to erosion may be expressed as a sequence of questions:

a. Fact finding. Is there catastropic erosion taking place? Is there continuous erosion, at rates believed to constitute a danger of soil degradation? If so, is adequate action being taken to prevent it?

   If the answers to either of the first two questions above are yes, and to the third no, then an erosion hazard exists. If there is found to be no serious erosion, the area concerned is "cleared".

b. Recognition. Is the existence of an erosion hazard, and the need for action, recognized: (a) by farmers, or other land users? (b) by government?

   If recognized by government but not by land users, then a campaign of education of users is called for. If not recognized (or not admitted) by government, then other than by representations there is little hope of progress. If both users and government accept there is a problem, then an erosion hazard is recognized.

c. Reasons for inaction. If an erosion hazard exists and is recognized, but there is presently no or insufficient action taken to control it, what are the reasons? These may include, in varying proportions, the following:

i. Lack of technical knowledge. If this is the main reason, it is a simple one on which to act, calling for technical assistance. It is almost invariably the case nowadays that appropriate and sufficient technical measures for control of any kind of erosion are known.

ii. Lack of finance. Where this is the main reason the solution is again straightforward, lying in financial aid for conservation measures, to farmers or government organizations. In this respect a difficulty may be to justify investment of scarce capital in erosion control, rather than in development measures which show more immediate returns.

iii. Action is not in the perceived interests of users. In developing countries users frequently treat land resources on a short-term basis, sometimes by force of necessity. If it is indeed in the best interests of the present land users, say over 10-20 years, to check erosion, then an education/publicity programme may help. In addition, however, there will almost certainly need to be action at government level.

iv. Institutional block. This refers to matters discusses above, whereby for reasons associated with tenancy, communal ownership, or other institutional or social factors, responsibility for care of soil resources lies with different individuals or groups than those who derive immediate benefit from their productivity. This may often be associated with reason no. 3. It is likely to prove the hardest reason on which to act, since land reform and/or legislation may be needed.

4. LAND USE AND EROSION: SOME EXAMPLES

A few examples may be taken, combining the technology of land use with land tenure and commenting on their relation to erosion. These are type-situations rather than case studies.

Semi-permanent cultivation of annual crops under communal village ownership, with supplementary livestock grazed on village common land. This is a widespread situation in tropical Africa. Former shifting cultivation has given place under population pressure to semi-permanent cultivation (and in many areas permanent cultivation also). Soil degradation, especially loss of organic matter, is probably widespread (although there is a serious lack of information on this). Over large areas, simple management measures such as contour ridging have to-date been sufficient to prevent catastrophic erosion. There is certainly sheet erosion, although we do not yet know whether it is at rates which ought to be regarded as serious. Severe erosion is localized, where population pressure has combined with soil of high erosion susceptibility. Examples are the severe sheet erosion in northern Ghana (Adu, 1972) and gullying in eastern Nigeria (Floyd, 1965). Overstocking has usually led to pasture degradation on valley grazing land, and this has in places led to gullying. In central Malawi, valley-floor (dambo) gullies have formed over the past 15 years.

Reasons for this state of affairs are a combination of perception, economics and institutional aspects. Soil degradation and continuous sheet erosion are not recognized. Where severe, the short-term need for the annual harvest compels continued cultivation without resting the land. Absence of physical conservation works is in part through lack of knowledge, in part economic. The erosion of common grazing land proceeds because it is in no individual's interests to check it, and social pressures inhibit joint village action.

Permanent cultivation of annual crops as a share-cropping tenant. This situation is common in the Indian subcontinent. Soil degradation is widespread, probably accompanied by sheet erosion. Catastrophic erosion is sometimes prevented by labour-intensive physical works, i.e. hand-built terraces. Erosion may often continue with little attempt to check it, however, with cultivation reaching right to the banks of active gullies.

Reasons for the lack of remedial action are well known. The landlord does not wish to spend apparently unproductive capital on a small part of his holding (if, indeed, he is aware of the erosion at all!). The tenant lacks finance, cannot spare the labour from the short-term need of next year's harvest, and above all has no incentive since improvements will not benefit him.

Latifundia, based on extensive ranching, coupled with cultivation of annual crops by labour tenants. Overstocking is not a problem, since it is in the interests of owners to use the land extensively. Tenants lack security of tenure, and have no incentive to prevent erosion where their plots prove to be susceptible. (It may be added that erosion on minifundia, or smallholdings, is not unrelated to the land pressure brought about by the high proportion of land in large estates; severe erosion in the Andean region of Venezuela is an example.)

Permanent cultivation on collective farms. This form of tenure, which can apply to a number of the technological classes, is included in a short list of examples on the grounds that it covers a substantial part of the developing world. I am almost totally without information, however, on the occurrence of erosion and measures taken to control it. Eroded and abandoned land is widespread in China, but this is a legacy of the past. In theory, the institutional means necessary to prevent or control erosion appear to be present, e.g. as communal labour guided by the village authority. It may well be that through human failings, practice sometimes differs from theory! The fact that the systems frequently include individual plots as well as the communal farm may have consequences.

Nomadic or semi-nomadic pastoralism on common land. This last example, largely found in Africa, illustrates in extreme form two common features. First, it is a method of land use formerly in equilibrium with the environment, but which with modern population increase has led to widespread vegetation degradation and frequently also erosion - e.g. sheet and gully erosion of inner valley sides in the savanna zone, wind erosion in the semi-desert region. Secondly, it exemplifies the situation in which it is not in the interests of any individual owner of livestock to improve the situation by restricting his herd, but indeed the reverse. Where cattle-owning peoples mingle with cultivators, as the Fulani and Hausa of northern Nigeria and adjacent countries, the institutional and social difficulties of erosion control become particularly complex.

SOME LINES OF RESEARCH

Directions of research directly or indirectly related to the relationship of erosion with traditional land use include the following:

- Field studies, including mapping, of the extent and severity of erosion and the conditions, both physical and human, with which it is associated. A sound geographical basis of this nature is an essential first stage.

- Detailed case studies of erosion, with a focus on the economic and institutional aspects of its past origin and present position.

- Research into rates of continuous sheet erosion, under permanent and semi-permanent cultivation. Rates of loss of the order of 0.5–1.0 mm/year, equivalent to 7–15 t/hectare/year, are commonly quoted as "acceptable" or "tolerable", but the geomorphological and pedological basis for this assumption is questionable. We do not yet know whether erosion at such rates will lead to irreversible soil degradation, and if it does, whether such effects are likely to be experienced after periods of the order of 10, 20, 50 or 100 years.

- Research into the extent to which soil organic matter levels have been lowered under permanent and semi-permanent cultivation, and the degree of structural deterioration or other adverse effects associated with this lowering (Young, 1976, pp. 115–121).

- Studies of the losses, of production and in economic terms, from erosion, and hence quantification of the benefits to be derived from conservation.

- Research into methods of land use that are intensive, conservational, and at the same time compatible with traditional practices, e.g. minimum tillage (Lal, 1974a, 1974b), the INEAC corridor system (Jurion and Henry, 1969), grass buffer strips (Roose and Bertrand, 1971).

- Studies of the effectiveness of different methods of controlling erosion, e.g. legislation (Christy, 1971), extension services, loans.

6. CONCLUSIONS

Few generalizations on this subject are possible, for each local case is likely to possess special features. It can be said, first, that whilst some forms of traditional land use are conservational, others possess features which, unless modified, are likely to lead under population pressure towards erosion. Unimproved shifting cultivation and uncontrolled nomadic grazing are examples. Secondly, whilst tenancy as such is not inherently conducive towards soil degradation and erosion, certain forms of it are; in general, the less secure the tenure, the more is there encouragement towards soil exploitation.

Since the above statements belong to the widely known truths referred to at the start of this review, it may be more useful to end on a methodological note. In any situation in which erosion is found, one of the answers to the questions given earlier is the "wrong" one. That is to say, erosion has not been recognized; the technical knowledge or the finance necessary for its control are lacking; action to control it is not in the interests, real or perceived, of users of land; or there is some institutional reason why such action is not taken. Having first determined where erosion is occurring, we should ask why — where, along the line from perception to action, is the will or the means for its prevention lacking?

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Paper No. 3

LAND CLASSIFICATION

by

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1. INTRODUCTION

Land classification is an extremely controversial subject due mainly to the complexity of the problem, the multitude of disciplines involved and the lack of definition and resultant misuse of terminology. The two words "land" and "classification" are an ambiguous pair. Land classifiers of all kinds think they know what the term "land classification" means; it is the work that they do. Unfortunately many of them undertake different kinds of work and so land classification becomes all things to many men. Definition is therefore of great importance.

2. DEFINITIONS

Both words in the title of this paper need to be defined namely - "classification" and "land". The first, classification, is the easier of the two to define: the placement of individuals together into mutually exclusive groups defined in terms of one or more attributes of the individual. The attributes may be morphological (e.g. shape, colour, chemical composition) or functional (e.g. productivity, suitability, erodability). While many phenomena are individuated in nature (e.g. animals, plants) land is a continuous body and for the purposes of classification must, at least in imagination, be divided into individuals. Thus for a morphological classification there may be red land and brown land, or steep land and flat land. Examples of a functional interpretation are goodland and badland or erodable land and non-erodable land.

The definition of land is not such a simple matter and has been the subject of many learned discussions and dissertations. The prodigeous Oxford Dictionary defines land as:

- the solid portion of the earth's surface,
- the ground or soil, especially as having a particular use or particular properties,
- a part of the earth's surface marked off by natural or political boundaries.

These definitions allow too wide and ill defined a concept for detailed consideration. The definition of land as agreed at the Wageningen meeting on land evaluation (1972), is considered appropriate for land classification purposes namely, a delineated area of the earth's surface: its characteristics embrace all reasonably stable, or predictably cyclic, attributes of the biosphere vertically above and below this area including those of the atmosphere, the soil and underlying geology, the hydrology, the plant and animal populations and the results of past and present human activity, to the extent that these attributes exert a significant influence on present and future uses of the land by man.

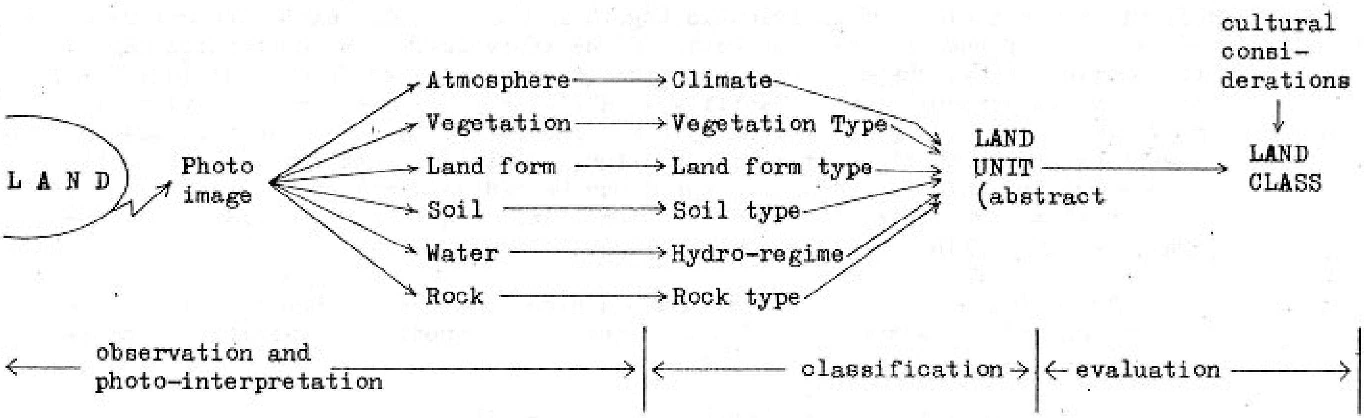
Land therefore involves:

- climate
- geology
- geomorphology
- soil
- vegetation
- populations and their effects.

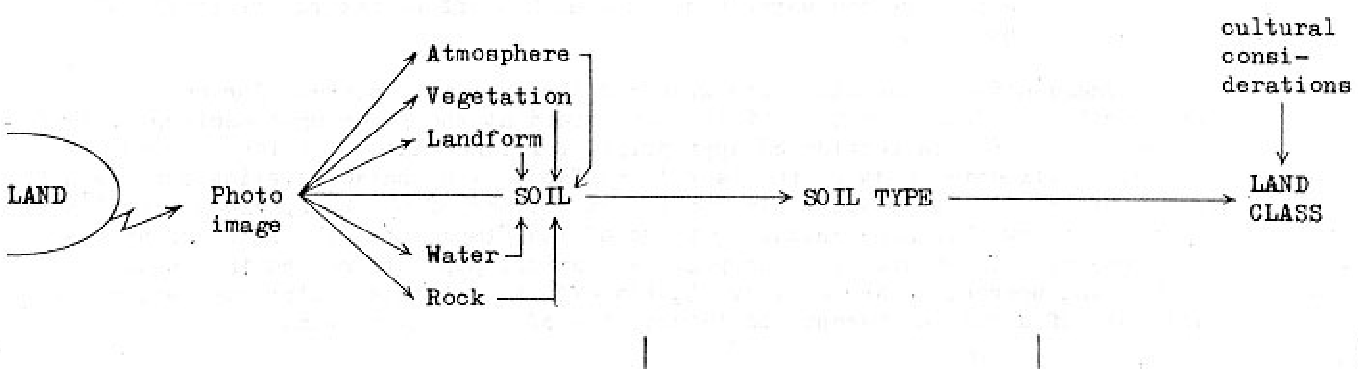
3. KINDS OF CLASSIFICATION

A land classification can emphasize any of the above attributes of land or their combination, according to the purpose of the classification. Zonneveld (1972) presents the following diagramatic comparison of holistic and single attribute surveys to arrive at a land resources classification, (simplified from original).

A. Holistic survey



B. Single attribute survey (example: Soil survey)



Young (1974) lists the following as subjects for classification of lands:

a. Agriculture

i. cultivation of a specified crop or crops, annual or perennial
ii. irrigated agriculture
iii. arable farming
iv. grazing, of unimproved or improved pastures.

b. Forestry

i. logging of natural forests
ii. forest plantations

c. Water resources

i. groundwater and surface water
ii. resources for irrigation

d. Mining

e. Engineering purposes

i. transportation purposes in general
ii. building foundations
iii. urban use

f. Recreation

g. Wildlife conservation (flora and fauna)

h. Special purposes

i. military purposes
ii. local government administration (e.g. assessment for taxation)

i. Multiple purposes

To this list may be added many far-reaching subjects such as agricultural adjustment, investment potential and environmental protection.

4. SCALES OF CLASSIFICATION

In addition to the different kinds of classification described, it is also necessary to recognise at least three different scale intensities in land classification activities, namely:

a. scales smaller than 1:250 000 comprising exploratory classifications

b. scales between 1:50 000 and 1:250 000 comprising reconnaissance classifications, and

c. scales less than 1:50 000 comprising detailed classification.

Vink (1975) has well illustrated scale concepts in land classification with the following table.

Table 1 SCALE CONCEPTS IN LAND CLASSIFICATION

Survey phase	Publishing scale of maps	Pilot projects	Planning stage	Decision to be taken
			Formulating targets	
Preliminary investigations for operational outline budget	Sketch maps		Stock-taking and re-formulating of targets	Choice of survey agencies; order 1st set of airphotos
Overall inventory of natural and human resources, indication of alternative level poss. and of priority	1:1 000 000 1: 250 000 (sample areas + areas 1: 50 000)	maps plan	Drafting of alternative action programs: Plan pilot projects	Choice of disciplines and members 1st team
		execution	First outline of dev. plan	Choice of preferable developments and of priority areas:
Semi-detailed survey of selected areas	1: 100 000 1: 250 000	execution		choices of survey disciplines and members 2nd team: order 2nd set of airphotos;
			Designing of plans 1st priority dev. areas	Choice of first priority development areas
Detailed surveys of confirmed development areas: Technical design of projects, financial estimates	1: 50 000 to 1: 5 000	evaluation	Second evaluation pilot projects: Implementation of continued projects	Confirmation of plans; choice of agencies for implementation and execution; choice of 3rd survey team and technical designing team.

The question of the scale of the classification is so important that it is considered beneficial to repeat the following table showing different soil survey classification scales as agreed between FAO and IBRD.

Table 2 GENERAL INDICATIONS OF SAMPLING DENSITY AND RATE OF PROGRESS ASSOCIATED WITH DIFFERENT INTENSITIES OF SOIL SURVEY

Draft FAO Soils Bulletin "Soil Survey for Irrigation Investigations" (1974)
(Systematic Soil Survey - with some use of Air-photo interpretation)

Kinds of Survey	Scale	Area Represented by 1 cm^2 of map	Density of Observations 1/ (0.5 obs./cm^2 of map).	Approx. Average Rate of Progress 2/ (per 20-day month)	Accuracy of Boundaries
Very High Intensity	1: 5 000	0.25 ha	1/0.5 ha	500 ha	Position of all boundaries checked throughout length on the ground
	1: 10 000	1.0 ha	1/2 ha	800 ha	
High Intensity	1: 20 000	4.0 ha	1/8 ha	1 250 ha	Position of almost all boundaries checked throughout length on the ground
	1: 25 000	6.25 ha	1/12.5 ha	1 500 ha	
Medium Intensity	1: 50 000	25.0 ha	1/50 ha	75 km^2	Some boundary checking - most inferred
Low Intensity	1: 100 000	1 km^2	1/2 km^2	200 km^2	Almost all boundaries inferred.

NOTES

1/ Density of observations: Figures represent the density of all soil observations averaged over the entire area of the map; (acceptable density usually ranges between 0.25 and 1.0 observation/cm^2 of map on this basis).

1/ Rate of Progress: Figures given represent an approximate average from the wide range of progress rates experienced in actual surveys.

5. EXAMPLES OF LAND CLASSIFICATION

In selecting examples, an attempt is made to differentiate between morphological and functional classifications and to illustrate both at various scales.

a. Morphological

Of the morphological classifications one of the most comprehensive on a global basis, is the World Atlas of Agriculture, produced by the Instituto Geographico de Agostini - Novara, under the aegis of the International Association of Agricultural Economists (1969). In the foreword to this work Professor Giuseppe Medici states - "the disparity and uneveness of previous material (present land use) makes it difficult, perhaps impossible, to compare situations between country and country and to detect common lines of development and transformation in agricultural reality". Herein, it is suggested, lies the purpose of the classification - to unify data presentation and compare country situations and detect common lines of development. Sixteen main categories of land are recognized namely: arable, rice, grass, coffee, tea, agave, spice, fruit and orchard, sugarcane, market gardens, rubber, woods and forest, forests and jungles, rough grazing, reindeer, grazing, and non-agricultural. Mapping is at the scale of 1:2½ million or 1:5 million for all countries except Africa and there are accompanying texts for all regions except Africa.

The Atlas of Physical, Economic and Social Resources of the Lower Mekong Basin prepared under the direction of USAID by the Engineering Agency for Resource Inventories and the TVA for the UN Economic Commission for Asia and the Far East (1968) contains a good example of a regional present land use classification. Sixteen divisions of present land use are again employed (from 1:50 000 base material) in the classification, rice lands being additionally classified into floating, single cropping, double cropping and upland. The main categories classified and mapped are: settlements, tree and perennial crops, cropland continual and rotational cropping, un-improved grazing, ten kinds of woodlands swamps and marshes and unproductive land. It is of interest to note that the additional detail on rice cultivation and the classificaion was based on an old International Geographic Union/land use system.

An example of a morphological classification at a more detailed country level, is the Landforms, Soils and Present Land Use Survey of the Indus Plains in then West Pakistan by the Resource Survey Division of the Photographic Survey Corporation of Toronto, Canada for the Columbo Plan Organization (1958). In the background to the report there appears the following statement - "officials and scientists in (West) Pakistan have long felt the need for a broad appraisal of the location, extent and characteristics of agricultural resources which would provide a firm foundation for formulating comprehensive policies and plans for agricultural development, for framing more detailed surveys and investigations and for planning and assigning priorities to irrigation and reclamation schemes. The object of this particular classification therefore was to provide the foundation on which to plan. This is borne out by H.G. Doin of McGill in his foreword to the report wherein he states "no cumulation of discontinuous detailed reports, no matter how accurate and how exhaustive they are for their particular areas, can replace an inventory of a large area even though of necessity generalized. A broad picture of the whole agricultural economy is necessary for wise country planning."

In the 401 page report and 77 accompanying maps, the present land use is classified in 9 main classes (settlement and non agric. land, horticulture, tree and perennial crops, cropland, improved permanent pasture, unimproved grazing, woodland, swamp and marsh and unused land) with a total of 12 subclasses. Taking the cropland class alone the subclasses used were: perennially canal irrigated, seasonally canal irrigated, seasonally flooded, torrent watered, dry cropped and well irrigated. The scale of mapping was 1:253,440.

The three examples cited are emminently professional pieces of work and well illustrate the need for the classifier to fit a local system to an existing and well recognized overall Framework. Without such control it is impossible to collate results. The IGU Typology of World Agriculture and the USGS Circular 61 are good examples of such Frameworks for present land use (morphological) classification.

b. Functional

It is probably true to say that every country in the world has a functional land resources classification, of one kind or another, as a planning tool to assess the potential for agricultural development. Many reviews have been made of the different systems employed, including Olson (Land Classifications) Search, Agriculture No.4, published by New York State College of Agriculture, 1974; FAO (Approaches to Land Classification), Soils Bulletin No. 22, 1974; Stewart (Land Evaluation), Papers of CSIRO Symposium, 1968 and FAO (Land Evaluation in Europe) Soils Bulletin 29, 1975.

A few examples, at consecutively larger scales of various systems are cited.

At a global scale one of the most simple and recent is that made by the PSAC (US President's Science Advisory Committee) in 1967 and quoted by Meadows (1974) in "Dynamics of Growth in a Finite World". That Committee classified the land of the world as follows:

Land suitable for cultivation (potential arable land)	3.2 billion hectares
Non arable land with grazing potential	3.6 " "
Non arable land with no grazing potential	6.3 " "
Total	13.1 billion hectares

The classification is functional, i.e. it concerns behaviour, in this case predicted suitability.

An example of a regional functional land classification is contained in the previously referred to Mekong Basin Atlas. In addition to the present land use classification, the study includes a land potential classification, wherein the land is classified as follows:

i. Areas with a capability of high yields per ha with the application of intensive management practices.

ii. Areas with a capability of moderate yield per ha (most areas require normal conservation practices) with the application of intensive management practices.

iii. *Areas predominantly* suitable for the production of forests - production capacity only adequate to produce good stands of timber.

iv. Land not suited for any other use.

At the detailed level there are a very wide range of classifications to consider one of the most widely used is that of the Soil Conservation Service of the USDA called "land capability classification" and described by Klingebiel and Montgomery in the U.S. Govt. Printer Office, Agric. Handbook No. 210. The classification is based on detailed soil surveys of 1:20 000 scale or larger and groups soil mapping units primarily on the basis of their capability to produce common cultivated crops and pasture plants, without deterioration, over a long period of time. The capability units used have similar potentials and limitations and are

Table 3

USDA, SGS LAND CAPABILITY CLASSIFICATION-AGRIC. HANDBOOK NO. 210
CLASS CHARACTERISTICS

Property/ Limitations from permanent features	CLASS							
	I	II	III	IV	V	VI	VII	VIII
Slope	Nearly level 1–2%	Gentle 1–2%	Moderately steep	Steep 16–30%	Nearly level stony/ rocky	Steep 16–30%; stony	Very steep more than 30%; stones	Stones
Erosion Susceptibility	Low	Moderate/ moderate past erosion	High	Severe/ severe past erosion		Severe/ past erosion	Erosion	Erosion/ erosion hazard
Damaging overflow frequency	None	Occasional	Frequent	Frequent	Frequent	Excessive		
Permeability (subsoil)			Very slow					
Wetness or waterlogging	Well drained	Wetness exists permanently	Some continuing water-logging	Excessive wetness/ continuing water-logging after drainage	Rainfed areas, not drainable	Excessive	Wetness	Wet
Depth	Deep; more than 36 in	Less than ideal; 20–36 in	Shallow; 10–20 in	Shallow; less than 10 in			Shallow	
Water holding capacity	Holds water well		Low	Low		Low		Low
Fertility	Well supplied with nutrients		Low					

Table 3 (cont.)

	I	II	III	IV	V	VI	VII	VIII
Salinity or sodium		Slight but liable to recur; crops slightly affected	Moderate; crops moderately affected	Severe; crops seriously affected	Crops seriously affected	Yes; crops seriously affected	Salts or sodium satisfactory growth impossible	Salinity or sodium
Climatic limitations	Favourable	Slight	Moderate	Moderate	Yes; limited growing season	Severe		Severe
Management requirements	Easily worked; ordinary management	Somewhat unfavourable workability unfavourable		Special treatment & practices	Proper management improved pastures	Intensive range; pasture improvement	Impractical to apply; range improvement	Protection management; does not give economic returns under any kind of management.
Examples of required (observation) practices	Fertilizers, conservation of crop residues	Special conservation practices easy to apply; terracing, strip cropping	Supply OM; more difficult	More difficult		Contour furrows, drainage ditches	Seeding for protection	

designated by a symbol such as III e-2. The lower case letter designates subclasses that have the same kind of limitation and the arabic letter indicates the capability unit which require similar management practices. Classes I-IV are generally considered to be land suited to cultivation and other uses; classes V - VIII are limited in use. Pertinent among the assumptions are the fact that the classification is meant for detailed surveys, for moderately high levels of management and is based on removal of non permanent limitations. A generalized summary of class characteristics is given in Table 3.

A somewhat similar methodology, with modified criteria, has been formulated for the Philippines and the main criteria for classification in this system are presented in Table 4.

Table 4 CRITERIA FOR ARABLE LAND CLASSES IN PHILIPPINES

Arable

Class	Slope percent (not steeper than)	Erosion Class (not more than)	Depth
A	3	1. Less than 25% topsoil lost; some rills may be present	Very deep (more than 150 cm)
B	8	2. 25-75% topsoil lost; small gullies may be present	Deep (100-150 cm)
C	15	4. All topsoil lost; land truncated by gullies	50-100 cm
D	25	4. All topsoil lost; land truncated by gullies	

from Hudson, 1971

Non arable

It is suggested that the systems cited have a number of basic features, namely:

a. the more severe the limitation the lower the class

b. grazing, pasture and woodland are not considered for the soils with few limitations

c. optimum economic use is not considered although implied

d. the socio-economic context of the area is not considered

e. the use is very broadly defined.

6. TRANSFERABILITY

The question of transferability of different classifications, to a specific area under investigation, is always a worrying question in resource surveyors' thoughts at the beginning and during the course of a survey and indeed sometimes after completion of a survey. Some surveyors/classifiers automatically apply the system with which they are most familiar, albeit that it was originally designed for different environment conditions. There are undoubtedly some advantages in using an existing classification. Firstly the classifier is aware of the methodology, assumptions and criteria of the system and confines his data collection to those land attributes which are essential to the classification and does not waste inputs in collecting unnecessary data. Secondly, and equally important, having previously used the system, he has customers who are used to presentation of the results in the "standard" format. A good example of this is the World Bank's requirement for the use of the USBR's land classification system for irrigation in assessing the feasibility of irrigation projects. Is such an approach, i.e. transfer of an existing system, with or without modifications, always the ideal one.

It is suggested that it is not. An example of recent work by FAO in Central Java illustrates this premise.

The project had, as one of its main objectives the demonstration and evaluation of the benefits of conservation techniques in several representative subwatersheds suffering from very serious erosion. The population density in the areas was exceptionally high (815 persons per square kilometer) and the terrain was flat to hilly with soils developed from volcanic tuff, alluvium from the tuff and limestone. Intense food crop cultivation and exploitation of land for export crops had resulted in the clearing of most hillsides. Average per capita income was exceptionally low and the average size of holding less than 0.4 ha per family (4.8 persons). The rate of erosion on non treated cultivated steep land has been calculated as up to 4 cm per year.

For various reasons, a detailed soil/land inventory was not carried out but a generalized soil map of the whole watershed, plus data on slope classes, permits reconstruction of the following simplified hypothetical soil and land inventory of a representative area (Table 5). Soils are named in accordance with the local classification used in the generalized soil map.

Table 5 HYPOTHETICAL SOIL AND LAND INVENTORY

Mapping Unit	Soils	PM	Slope (percent)	Depth (cm)	Elevation	Percent of area
1.	Andosols (normal phase)	Volcanic ash	16 - 30	more than 50	above 750m	10
2.	Andosols (steep phase)	Volcanic ash	more than 30	less than 50	above 750m	20
3.	Lithosols (normal phase)	Mixed	16 - 30	less than 10	all elevations	5
4.	Lithosols (steep phase)	Mixed	more than 30	less than 10	all elevations	30
5.	Mediterranean (normal phase) stony	Lime-stone	16 - 30	more than 50	below 750m	5
6.	Mediterranean (steep phase, stony)	Lime-stone	more than 30	less than 50	below 750m	20
7.	Alluvial (normal phase)	Alluvium	less than 5	more than 100	below 750m	5
8.	Alluvial (flooded phase)	Alluvium	less than 5	more than 100	below 750m	5

Application of the two described detailed classification systems, to the above inventory, results in the following Land Capability Assessments for the representative area.

Table 6

HYPOTHETICAL LAND CLASSIFICATION

	Percent of Area	
	USDA System	Philippines System
Soils that can be cultivated safely with ordinary good farming practices, i.e. Class 1/A	5	5
Soils that can be cultivated with easily applied practices, i.e. II/B	5	5
Soils that can be used regularly provided they are given the proper treatment, i.e. Class III/C	0	0
Soils that may be cultivated occasionally if handled with care, i.e. Class IV/D	10	20
Soils that should be used for pasture or forestry i.e. Class V/L	0	0
Soils that should be used for grazing or forestry capable of producing forage or woodland if properly managed i.e. Class VI/M	5	70
Soils that should be used for woodland if rainfall is adequate, otherwise for grazing i.e. Class VII/N 45	45	
Soils that should be used for wildlife, recreation, or watershed uses i.e. Class VIII/X or Y	30	0

In summary these two particular classifications, if applied, would give the following "recommendations".

	USDA	Philippines
Arable Land	20	30
Non-arable Land	50	70
Non-agricultural Land	30	

Such action for the Central Java area is simply not practical. If the land/project area had been in Central Sulawesi the classification might have been applicable. However, to take some three-quarters of the total land area out of arable cultivation would result in at least famine in Central Java. Other solutions and actions are necessary and indeed have been found and implemented.

The following are the economic results of bench terracing on various lands in the project area.

Table 7 PROVISIONAL PROFITABILITY CRITERIA OF BENCH TERRACING FOR DRYLAND CULTIVATION CENTRAL JAVA

Land above 1 000 m

Benefit - cost ratio 1/ at 12 percent interest rate

Soil Depth \ Slope	0 - 5 percent	5 - 30 percent	30 - 50 percent
75 - 100 cm	12.5	6.1	2.8
50 - 75 cm	7.4	3.5	1.7
25 - 50 cm	2.4	1.2	0.6
Averages (all depths)			
Total labour (m/d per ha)	280	934	1 862
Total cost (R_p/ha)	91 245	223 020	415 275

1/ Computed by dividing the total present value of project costs into the total present value of project benefits.

The figures show that, within the socio-economic context of the area, it is indeed practical and profitable to bench terrace certain lands of more than 30 percent slope. Accordingly, for a land classification in Central Java, the criteria for classification must take this fact well into account.

This fact in no way detracts from the correctness, or implies any criticism of the two detailed classification systems previously described. It does however emphasize the fact that their criterion, like those of most systems, are most applicable to the areas that they were designed to classify and do not automatically have general application.

7. A COMMON METHODOLOGY

Is there a universally applicable system for land classification? If the meaning of system implies establishment of universally applicable criteria - the answer must surely be no. There is however a methodology whose principles, it is believed, can be applied to a very wide range of circumstances. The methodology has been developed by two multidisciplinary groups, one in Wageningen and one in FAO, over the past six years and the first version of the methodology has been published, entitled "A Framework for Land Evaluation". FAO (1973). Publication of an improved version is anticipated in 1977.1/

In the proposed methodology land evaluation is defined as the process of collating and interpreting basic inventories of soil, vegetation, climate and other aspects of land in order to identify and make a comparison of promising land-use alternatives in terms applicable to the objectives of the evaluation. In summary a multidisciplinary approach is recommended and basic to the concept is recognition of the fact that land evaluation is meaningful only in relation to a clearly defined use. The framework recommends qualitative and quantitative classifications of land for well defined land utilization types under unimproved and improved conditions, by suitability orders, classes, subclasses and units. A single stage (physical and socio-economic studies together) approach or a two stage (physical studies followed by socio-economic studies) is allowed for. The framework is intended to provide an outline of principles and terminology within which local systems of land evaluation may be formulated.

Copies of the new publication will be available shortly and it is not the object of the present paper to go into details of the proposed methodology. However it is believed that the 6 basic principles of the Framework are pertinent to the subject of the consultation.

The six principles are:

a) Land suitability assessment is only meaningful with respect to specified kinds of use. This principle embodies recognition of the fact that different kinds of land use have different requirements. As an example, an alluvial floodplain with impeded drainage might be highly suitable for rice cultivation but not suitable for many forms of agriculture nor for forestry.

   The concept of land suitability is only meaningful in terms of specific kinds of land use, each with their own requirements, e.g. for soil moisture, rooting depth etc. The qualities of each type of land, such as moisture availability or liability to flooding, are compared with the requirements of each use. Thus the land itself and the land use are equally fundamental to land suitability evaluation.

b) Evaluation requires a comparison of the benefits obtained and the inputs needed on different types of land. Land in itself, without inputs, rarely if ever possesses productive potential; even the collection of wild fruits requires labour, whilst the use of natural wilderness for nature conservation requires measures for its protection. Suitability for each use is assessed by comparing the required inputs, such as labour, fertilizers or road construction, with the goods produced or other benefits obtained.

1/ Framework for Land Evaluation. Soils Bulletin 32. 1977 FAO Rome.

c) A multidisciplinary approach is required. In particular, suitability evaluation always incorporates economic considerations to a greater or lesser extent. In qualitative evaluation, economics may be employed in general terms only, without calculation of costs and returns. In a quantitative evaluation the comparison of benefits and inputs in economic terms plays a major part in the determination of suitability. It follows that a team carrying out an evaluation require a range of specialists. These will usually include natural scientists (e.g.) geomorphologists, soil surveyors, ecologists), specialists in the technology of the forms of land use under consideration (e.g. agronomists, foresters, irrigation engineers, experts in livestock management), economists and sociologists. There may need to be some combining of these functions for practical reasons, but the principle of multidisciplinary activity, encompassing studies of land, land use, social aspects and economics, remains.

d) Evaluation is made in terms relevant to the physical economic and social context of the area concerned. Such factors as the regional climate, levels of living of the population, availability and cost of labour, need for employment, the local or export markets, systems of land tenure which are socially and politically acceptable, and availability of capital, form the context within which evaluation takes place. It would, for example be unrealistic to say that land was suitable for non-mechanized rice cultivation, requiring large amounts of low-cost labour, in a country with high labour costs. The assumptions underlying evaluation will differ from one country to another, and to some extent between different areas of the same country. Many of these factors are often implicitly assumed; to avoid misunderstanding, and to assist in comparisons between different areas, such assumptions should be explicitly stated.

e) Suitability refers to use on a sustained basis. The aspect of environmental degradation is taken into account when assessing suitability. There might, for example be forms of land use which appeared to be highly profitable in the short run but were likely to lead to soil erosion, progressive pasture degradation, or adverse changes in river regimes downstream. Such consequences would outweigh the short-term profitability, and cause the land to be classed as not suitable for such purposes. This principle by no means requires that the environment should be preserved in a completely unaltered state. Agriculture normally involves clearance of any natural vegetation present and normally soil fertility under arable cropping is higher or lower, depending on management, but rarely at the same level as under the original vegetation. What is required is that for any proposed form of land use, the probable consequences for the environment should be assessed as accurately as possible and such assessments taken into consideration in determining suitability.

f) Evaluation involves comparison of more than a single kind of use. This comparison could be for example, between agriculture and forestry, between two or more different farming systems, or between individual crops. Often it will include comparing the existing uses with possible changes, either to new kinds of use or modifications to the existing uses. Occasionally a proposed form of use will be compared with non-use, i.e. leaving the land in its unaltered state, but the principle of comparison remains. Evaluation is only reliable if benefits and inputs from any given kind of use can be compared with at least one, and usually several different, alternatives. If only one use is considered there is the danger that, whilst the land may indeed be suitable for that use, some other and more beneficial use may be ignored.

It is suggested that if the principles and methodology of the Framework had been applied to a classification of the project area, the results of a classification in Central Java for upland soils might have looked as in Table 8.

Table 8 HYPOTHETICAL POTENTIAL SUITABILITY CLASSIFICATION FOR VARIOUS LUT'S

Land Utilization Type	more than 50 cm	less than 50 cm	less than 10 cm		more than 50 cm	less than 50 cm
	normal phase	steep phase	normal phase	ssteep phase	normal phase	normal phase
Pine/Albizzia/Elephant grass/cattle (3) rehabilitation, hand labour; 30 year cycle	S_1 (2.4)	S_2 (1.7)	S_2	S_2 (1.2)	S_1 (2.4)	S_2 (1.9)
Eucalyptus/Elephant grass/ cattle/rehabilitation, hand labour, 40 year cycle,	S_2 (2.0)	S_2 (1.3)	S_2	S_2 (1.1)	S_2 (1.5)	S_2 (1.0)
Acacia auriculiformis plantation, hand labour, 10 years cycle	S_2 (1.8)	S_2 (1.2)	S_2	S_2 (1.5)	S_2 (1.6)	S_2 (1.4)
Bench terracing rehabilitation, hand labour with fertilizer, cultivation of maize, sorghum and groundnuts.	S_1 (8.0)	S_1 (2.2)	S_2 (1.2)	NS (0.6)	S_1 (5.5)	S_2 (1.4)

S_1= Suitable S_2= Marginally Suitable; NS= Not Suitable
(Benefit-cost ratios)

In terms of arable land, this would "allow" arable cultivation of some 35 percent of the area if the S_1 criteria of suitability were used, or 60 percent of the area if the S_2 criteria of suitability were used. These figures are in marked contrast to those calculated previously from the other classification systems, even omitting the alluvial lands.

8. CONCLUSIONS

There is an exceptionally wide range of land classifications that are not comparable because of differences in the methodologies, criteria and assumptions used. Seldom can an existing land classification successfully be used in an environment markedly different to the area for which it was designed. Use of existing frameworks is recommended in formulating both morphological and functional land classifications to meet specific area requirements, so that results can be collated with other formulations. For functional classifications the use of the Framework for Land Evaluation is recommended to ensure that important socio-economic factors are well taken into account in classifying land for optimal agricultural use.

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Paper No. 4

SOIL CONSERVATION AS A PROTECTIVE MEASURE AGAINST SALINIZATION

by

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1. THE WIDER SCOPE OF SOIL CONSERVATION

The historical concept of soil conservation is exclusively related to the erosion processes, their physical effects on land, vegetation and agriculture, and the consequent economic, social and human welfare aspects of the erosion problem (Bennett, 1939). The early American soil conservationists recognized erosion as the major cause for rendering eroded soils unproductive and they pleaded for the preservation of the most precious natural resource, the soil (McDonald, 1941).

The concept of soil conservation, nowadays, has been expanded to mean:

i. protection of the soil against physical loss by erosion or against chemical deterioration; that is, excessive loss of fertility either by natural or artificial means, and

ii. a combination of all management and land use methods which safeguard the soil against depletion or deterioration by natural or by man-induced factors (Soil Science Society of America, 1971).

The use of the soil conservation term in this sense includes the preservation of the remaining good qualities of the land and the restoration of those qualities where they have been destroyed by man-made or natural forces.

The wider scope of soil conservation, therefore, considers erosion as only one of the ways that may cause degradation of virgin and cultivated soils. The other processes that may render soils partially or completely unproductive include salinization, sodication, waterlogging, reduction of permeability, loss of fertility, infestation with noxious plants and misuse of herbicides and pesticides. The restoration of these forms of soil degradation and the protection from their hazards call for the application of certain conservation measures and the undertaking of necessary precautions. Conservation tools such as contouring, terracing, strip cropping, planting cover crops, selection of proper crop rotations, application of fertilizers, and drainage are quite often mentioned in the literature as the techniques which help to protect or improve the land.

It is the purpose of this paper to outline some of the conservation measures and precautions that are related to protection of soils against salinization. It may be noticed that some of the conservation tools presented herein are not different from what is normally known as management practices for salinity control. The paper is not meant to be a comprehensive study on the subject but rather an example illustrating how under the domain of soil conservation a condition other than erosion can be handled.

2. SELECTION OF THE SUITABLE SOIL

The right selection of soils for agricultural development is the very fundamental conservation measure, not only for the natural land resource but also for the capital investment. In the conservation farm plan, given by Reese (1966) as the first soil and water conservation practice, the essentiality of a detailed soil survey was stressed in order to use the land according to its capabilities and to treat it according to its need for continued production. Conservation of newly developed lands from salinization should start as early as the stage of project planning and site selection. It is a normal practice, under arid and semi-arid climates, to examine at the time of surveying those land qualities and soil characteristics pertinent to salinity, sodicity and waterlogging, and to make a preferential selection of the site considering the absence of these problems or the ease with which they can be treated.

The selection of the soil should be based not only on its present but also on its future condition (Maletic & Hutchings, 1967). The standard soil survey, when guided by certain prognostic principles, becomes an important conservation tool that provides early warning against future salinity problems (Massoud, in press). The principle of prediction accounts for the possible changes in the salt balance when the soil is brought under cultivation, especially if irrigated. Emphasis should also be placed on these changeable characteristics arising from water and land development. Furthermore, it may happen that salinization and sodication are not present within the normal depth of soil surveying or the boundaries of the project but the soil becomes salt affected later on. As a precaution principle, it is necessary to extend the investigations to deeper substrata and consider the land characteristics of the area outside the project boundaries and the future development.

3. MONITORING OF SALINITY

The frequent checking on the soil characteristics affecting its productivity is a proper exercise that provides an early warning against soil degradation. Monitoring in this sense can be considered as a protective measure and, therefore, its role as one of the conservation tools should not be underestimated. Various soil and hydrological surveys, field investigations and laboratory analyses are usually undertaken to diagnose soil salinity and when they are used for monitoring, with a predictive objective, they become useful prognostic methods. Although the basic surveys and investigations provide the essential data on the soil, water, crops, climate, management and other parameters affecting the salinization process, monitoring is quite often concerned with the following most effective factors and changing properties:

soil:	salinity, salt composition, ESP, pH
water:	quantitites, salinity and salt composition of influent and effluent waters
soil-water:	depth to water table, infiltration rate and hydraulic conductivity
climate:	parameters affecting evapotranspiration, rainfall
crops and management:	crop performance and yield, agronomic practices and salt leaching.

Monitoring of salinity by the routine survey and laboratory analyses is a tedious and costly exercise. The development of the in situ 4 - electrode soil conductivity technique has overcome these difficulties (Rhoades, 1976). Similarly, the use of remote sensing techniques, if proved to be applicable to diagnosis and monitoring of salt affected soils, will cause a breakthrough in the time scale and extent of coverage since it is possible to monitor in an 18 day cycle an area of about 5.6 million ha (9.5 x 9.5 inch frame) with the Earth Technology Research Satellite.

4. WATER MANAGEMENT PRACTICES

The salinity of the soil is largely dependent on its moisture regime. Water does not only add salts to the soil but also helps in moving them away from the rootzone and it is the balance between the added and the removed quantities that determine the trend towards salinization or desalinization of the soil. Adoption of good water management practices can assure a favourable salt balance and conservation of the soil productivity. The main conservation tools in this regard may be presented under the following headings.

4.1 Irrigation

Except under dry farming, irrigation water in the arid and semi-arid areas is one of the main contributors to the soil moisture regime. The quality, amount, frequency and method of application affect the salinity status in the soil. Even where a relatively good quality water (200 ppm) is applied at the normal rate of 10 000 m^3/ha/year a salt load of about 2 tons/ha might precipitate in the soil upon drying. Fortunately, a great portion of this quantity can be leached from the rootzone with the proper management practices. Anticipation in advance of the problems that may arise from using irrigation water of unfavourable quality will help use alternative measures to reduce the risk of soil salinization. As a guide, a water may have no problem, increasing problem and severe problem as to its salinity if the EC_{iw} is <0.75, 0.75 - 3.0 and >3.0 mmho/cm, respectively (Ayers & Westcot, 1976).

The quantity of irrigation water varies with the kind of crops, its stage and season of growth and the abundance or scarcity of the water itself. Generally, watering dilutes the salt concentration and if applied in excess of that needed to replenish the soil reservoir to its field capacity water usually leaches salts from the rootzone, in a well drained soil. On the contrary, if water is thinly spread over large areas salinization will most probably occur. As a precautionary measure, water abundance, although advantageous, should be properly managed to keep a favourable balance between the salt content in the rootzone, the depth to water table and the groundwater salinity. In case of water shortage, the use of irrigation methods capable of distributing lower quantities with higher efficiencies, sprinkler and drip irrigation, should be encouraged. Otherwise, the irrigated area has to be limited and efficiently wetted.

The frequency of irrigation affects the salt balance between two irrigations. The longer the interval, the drier the soil and the higher the salt concentration will be. So, where salinization is probable more frequent irrigation, if technically and economically feasible, can reduce the effect of moisture stress on the crop.

The various methods of irrigation, being different in the rate of water application, the uniformity of moisture distribution and the wetted area of the soil surface, will affect differently the salt regime of the soil. In flood or spate irrigation salts tend to move away from the rootzone. In basin or border irrigation, where water is spread to cover a certain surface area of the field, the amount of salts removed is more dependent on the quantity of water and its uniformity of distribution. As a precautionary measure against salinization, the irrigation system should be designed to provide a uniform moisture distribution through land shaping and adjusting the surface slope, size of water stream and length of run.

Although furrow irrigation provides a better control of moisture distribution and percolation losses, salts may accumulate on top of the ridges between furrows. It is possible to overcome this problem by changing the places of the furrows, alternating furrow irrigation with border or basin irrigation, changing the bed shapes and planting site. Sprinkling has the advantage over the above mentioned methods, of distributing low norms of water uniformly over the field. Moreover, water will move under unsaturated condition and thus be more effective in leaching salts (Nielsen et al, 1965). Trickle irrigation has the same advantages as sprinkling, especially if the lines are closely spaced. However, salts tend to concentrate midway between plants and at the wetting front between the lines of drip emitters (Bernstein & Francois, 1975). In absence of sufficient rainfall to leach the accumulated salts, trickle irrigation has to be supplemented by sprinkling or other surface irrigation methods to reduce salt accumulation in the uncultivated portions of the field.

4.2 Leaching of salts

Leaching is the most effective process by which salt affected soils are restored to normal and the salinity of the cultivated soil is kept under control. The efficiency of this process depends on the quality and quantity of the water used in leaching, the ease with which it percolates through the soil, and the removal of the leached salts in the drainage stream or their accumulation beyond the active rootzone. The use of poor quality water for irrigation entails the application of higher leaching requirements. Realizing the dual effect of leaching, namely soil desalinization and increasing the salt load of the groundwater or return flows, the recent trend is to minimize the leaching requirements (Bernstein & Francois, 1973; Rhoades, 1974). In this case, the leaching requirements previously recommended by the USSL staff, Agricultural Handbook No. 60 (1954), can be reduced to one-fourth and consequently the crop tolerance limits be increased 4-fold. The applicability of the minimum leaching requirements to control soil salinization needs efficient management of irrigation and drainage systems to keep the salts pushed downward and to minimize the upward water flux, otherwise the risk of salinization will be higher whenever the irrigation or drainage system goes wrong.

A less risky as well as a less conservative approach which seems to be more convenient and effective in controlling salinization is that proposed by Rhoades (1974), where the leaching requirement (LR) takes into account the average salinity of the rootzone (EC_e) at a given permissible reduction in crop yield, the salinity of irrigation water (EC_{iw}) and that of drainage water (EC_{dw}) as given:

$$LR = \frac{EC_{iw}}{5EC_e - EC_{iw}}$$

Data are available on the relation between the permissible reduction in crop yield, soil salinity, irrigation, water salinity and the leaching requirements (Ayers & Westcot, 1976). Such information can be considered as a guide to better conservation of irrigated soil against salinization.

Leaching of salts from rainfed agricultural soils depends in the first place on intensity, duration and frequency of precipitation. In the arid and semi-arid regions, other conservation measures have to be taken to encourage the relatively limited rainfall to penetrate into the soil and induce leaching. It may be feasible to count upon rainfall for leaching if the maximum rains fall in a defined season with sufficient amounts as is the case under a Mediterranean climate. Otherwise, the availability of a supplementary system of irrigation, which is always an advantage, will help in salt leaching.

4.3. Drainage

Surface drainage was recognized by the early conservationists as a means of getting rid of excess water on the soil surface, runoff, and controlling erosion if the drainage channels were properly located. As a conservation measure against salinization, subsurface drainage plays an essential role in carrying away the excess waters percolating through the soil, reducing the water table level and minimizing its fluctuation above a critical level. The drainage water has usually a higher salt content than that of irrigation and if measures are not taken to discharge it away from the rootzone the rising watertable becomes a continuous source of soluble salts and induces soil salinization.

In order that a drainage system fulfills its objectives, it should be designed properly to account for discharging the percolated water in excess of the evapotranspiration requirement (inefficient irrigation losses, leaching, seepage, rain storms), taking into consideration the rooting depth of the major crops in the rotation, the rate of capillary rise, salinity of the groundwater, and it has to be economically justified. The most important factor in efficient drainage is the maintenance of the watertable depth below the critical level. Kovda (1973) relates this critical depth to the salt content of the groundwater in the arid zone and areas provided with irrigation and drainage as, respectively, being 2 - 2.5 m when the salt concentration is 10 - 15 g/l, and 1 - 1.5 m for a less mineralized groundwater, 1 - 2 g/l. This critical depth also varies with the transmitting properties of the soil and may be considered for a maximum upward flux of 0.1 cm/day as ranging from 75-100, 175-200, and 90-120 cm for loam, fine sandy loam and sandy soils, respectively (Van Schilfgaarde, 1976).

When drainage water is not of poor quality it can be mixed with river water to supplement the limited water resources downstream. Nevertheless, the water quality of irrigation return flow has to be carefully monitored in order not to pollute the water downstream and cause soil salinization. Mixing of poor and good quality waters should be economically justified, considering the expected increase in crop production and the changes in the soil characteristics. Under the circumstances of a limited fresh water supply, drainage water may be used to leach and reclaim salt affected soils.

Drainage is often required where the danger of seepage exists. This has to be watched in case of land terracing or levelling for conservation practices. An interceptor drain can save vast areas at a lower level from salinization.

5. AGRONOMIC AND SOIL MANAGEMENT PRACTICES

When the soil conservation principles call for using the land according to its needs for a continued production one has to think in terms of improving the soil, protecting it from deterioration, and if these are not deemed possible, of how to live with the problems and avoid or minimize their harmful effects. Some of the following practices are conservation tools that seem to be concerned more with the latter objective. Others are followed for reasons less related to salinity control but they may indirectly cause soil salinization and therefore they have to be practiced taking into consideration their side effects.

5.1 Crop selection and rotation

The difference between plants in their relative tolerance to salinity provides the land user with a wide choice to select the most suitable crops for a given soil salinity and even with an advanced knowledge of the expected yield under this condition. Data on crop tolerance to salinity are available (USSL staff, 1954; Ayers & Westcot, 1976; Maas & Hoffman, in press) and they have to be used as a guide keeping in mind the various factors influencing the crop tolerance. These factors include the climate, plant species, varieties and stage of growth, and cultural conditions. Moreover, the economic value of the crop has to be considered in combination with its tolerance. Growing a sensitive crop on a moderately saline soil will not give its optimum yield as that of a moderately tolerant one, but it may happen that even with the permissible reduction in yield of the former, its net return will be higher than that from the latter.

As a general rule, the relative yield (Y) of a given crop at any given salinity (EC_e) was found by Maas and Hoffman (in press) to follow the equation:

$$Y = \frac{100\ (EC_e - EC_e\ )}{EC_o - EC_{100}}$$

where EC_{100} is the salinity threshold value (EC_e where Y = 100) and EC_o the salinity at zero yield (EC_e where Y = 0).

The quantitative salt tolerance rating for a wide range of crops based on their figures is given in a tabulated form in the Annex. According to the available data the relationship between crop salt tolerance and the range of EC_e at 75% and 50% relative yields may be summarized as follows:

Crop salt tolerance rating	EC_e at a relative crop yield of 75%	EC_e at a relative crop yield of 50%
Sensitive	< 3 mmho/cm	3 - 6 mmho/cm
Moderately sensitive	3 - 6 "	6 - 9 "
Moderately tolerant	6 - 9 "	9 - 15 "
Tolerant	9 -15 "	15 - 21 "

Since plants do not differ only in their tolerance to salinity but also in their water requirements, season of growth, rooting depth and moisture extraction patterns, and cultural requirements, it is to be expected that the soil characteristics will be affected differently under various crops. The selection of the right crop rotation is a successful conservation tool that improves the physical, chemical and nutritional qualities of the soil. The land user, therefore, can reduce the salinity hazards by including whenever possible crops like rice, berseem and those requiring frequent irrigation to help leach out salts.

5.2. Planting

Adjustment in planting techniques can modify the effect of salinity on crops, especially during the germination and seedling growth stages. Furrow row crops will withstand salinity better when planted in the irrigation furrow where crusting is not a problem, on the side of a sloping bed, near the edges of a double-row bed, on top of a single-row bed, in decreasing order of effect. Increasing the depth of irrigation water in the furrow and continuing irrigation until the wetting front has moved past the seed row on sloping beds are recommended practices for salinity control around the seeds. Broadcasting or drilling of seeds on flat fields when followed by a heavy irrigation is also practised to overcome salinity effects on germination. Increasing the rate of seeding, as a precautionary measure, is also practised in salt affected soils.

5.3 Land levelling and tillage

Land levelling is an essential operation to prepare land for irrigation by surface methods. It is also practised in combination with other measures for rainfed agriculture to reduce surface runoff and erosion. Where salinity may develop, the depth of soil as well as the micro-relief after levelling have to be carefully considered. Shallow profiles may lead to secondary salinization and therefore require more efficient water management. Changes in the micro-relief in the order of less than 30 cm result in increasing salt content on the raised spots and better leaching in the dips. Repeated land shaping before cropping will help to eliminate these variations and their effect become less obvious.

Tillage is one of the mechanical operations that serves numerous purposes including those of seed bed preparation and improvement of soil permeability. Since water infiltrates into and percolates through a tilled soil at a faster rate than in non-disturbed one, tillage will help salt leaching as well as water storage which is rather important in rainfed agriculture. However, repeated tillage to the same depth, especially in heavy textured soils and at above adequate moisture content aggravated by using heavy machinery, can create a dense plough-layer that causes temporary waterlogging followed by salinization. Variations in depth of ploughing and subsoiling are practices to avoid or alleviate the formation of this layer.

Ploughing can be done by various implements that not only affect differently the soil bulk density and aggregate stability but also the distribution and mixing of salts. Improving permeability and enhancing salt removal can be achieved by chisel and mould-board ploughs more effectively than by a disc harrow. Deep-ploughing implements would turn a salty layer and bring it up closer to the surface and therefore such operation has to be carefully investigated before proceeding on a full scale.

In areas susceptible to erosion, whether by wind or water, tillage operations have to be carried out with minimum disturbance to the soil surface or pulverization of the soil aggregates. The advantages and risks of tillage have to be carefully weighed and evaluated.

5.4 Fallowing and mulching

The land may be left fallow for some time where availability of irrigation water becomes a limiting factor for crop production, or under dry farming to preserve the soil water for a subsequent crop. A fallow land is more liable to salinization than a cultivated one since the cultural operations, especially irrigation, will tend to reduce or reverse the process. When fallowing is practised, factors affecting soil salinization such as depth and quality of groundwater, atmospheric evaporative demand, transmitting properties of the soil, length and frequency of fallowing, and measures taken to check water and salt movement upward should be carefully assessed.

The danger of fallowing becomes greater the shallower the depth to water-table will be. Theoretically, evaporation from a dry surface of a fine sandy loam soil would proceed at a rate of about 8, 3 and 1 mm/day if the water table is kept at 90, 120 and 180 cm respectively (Gardner & Fireman, 1958). The effect will be augmented with increasing the salinity of the groundwater and the evaporativity of the atmosphere. Summer fallow should be avoided under these conditions or otherwise carefully managed. Surface mulching and grouping irrigated and fallow areas separately and arranging them in such a way to reduce unnecessary circulation and rise of groundwater are precautions against salinization during fallow periods.

Mulching, as more frequently practised to conserve soil moisture under dry farming, would be a useful practice for reducing surface soil salinization. Surface tillage, maintenance or surface application of crop residues and placement of gravel are among mulching practices. The effectiveness of mulching in checking salinization depends on the factors affecting the processes as given above and on the right mulching techniques. Since mulching is also related to wind erosion control, practices such as minimum or zero tillage as a measure for conserving water and controlling erosion should be carefully assessed where the threat of salinization exists.

6. CONCLUDING REMARKS

Soil conservation is thought of by most planners and land users in terms of soil erosion and its control. Recently, other forms of land degradation, including salinity, have been considered by conservationists and International Organizations interested in environmental studies. However, the majority of land users in developing countries are not completely aware of the role certain conservation tools and management practices can play in safeguarding their soils against salinization. It is the responsibility of national institutions through the extension service media to encourage the farmers to apply practices as those given in the paper.

Adopting the concept of living with the salinity problem, if measures are not available to combat it, as a conservation principle may be the only way to a continued crop production and, therefore, the related practices should not be underestimated.

Salinity may be a side effect of certain conservation measures and cultural practices, which may be true for other degradation forms. Consequently, soil conservation has to be practised in an integrated manner taking into consideration other factors affecting land productivity.

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Salt tolerance of crops

(adapted from Maas & Hoffman, in press)

CROP	Tolerance rating	EC_e (mmho/cm); range at a relative crop yield of 75%	50%
Grain crops			
maize, rice	moderately sensitive	3 - 6	5 - 10
wheat	moderately tolerant	6 - 10	10 - 15
barley	tolerant	10 - 15	15 - 21
Sugar, Fibre & Oil Seed Crops			
sugar cane	moderately tolerant	6 - 10	9 - 15
sugar beet	tolerant	10 - 15	15 - 21
flax	moderately sensitive	3 - 6	5 - 10
cotton	tolerant	10 - 15	15 - 21
peanut (groundnut)	sensitive	<3	5
soybean	moderately sensitive	3 - 6	5 - 10
Forage Crop-Legumes			
cowpea, clover (ladino, red, strawberry), broadbean, common vetch, alfalfa, sesabania	moderately sensitive	3 - 6	5 - 10
berseem clover, birdsfoot trefoil	moderately tolerant	6 - 10	10 - 15
Forage crops - grasses			
meadow foxtail, lovegrass, maize	moderately sensitive	3 - 6	5 - 9
orchard grass, harding grass, rye grass, barley, fescue, (tall), Bermuda grass	moderately tolerant	6 - 10	9 - 15
Forage crops - grasses			
wildrye, beardless, wheatgrass, fairway	moderately tolerant	6 - 10	9 - 15
Sudangrass, wheatgrass (crested), wheatgrass (tall)	tolerant	10 - 15	15 - 21

cont.

<u>Vegetable crops</u>		<u>75%</u>	<u>50%</u>
bean	sensitive	<3	5
pepper, lettuce cucumber, cabbage, tomato, broccoli, spinach	moderately sensitive	3 - 6	5 - 9
<u>Root crops</u>			
onion, carrot	sensitive	<3	5
reddish potato	moderately sensitive	3 - 6	5 - 9
garden beet	moderately tolerant	6 - 10	9 - 15
<u>Fruit & Nut Crops</u>			
strawberry, apricot, blackberry, boysenberry, peach, almond, plum	sensitive	<3	5
grapefruit, orange, grape	moderately sensitive	3 - 6	5 - 9
date	moderately tolerant to tolerant	6 - 10	15 - 20
<u>Other crops lacking sufficient data for quantitative rating</u>			
apple, avocado, lemon, okra, raspberry	sensitive		
lentgrass, millet (foxtail), Rhodesgrass, timothy	moderately sensitive		
bromegrass, canarygrass (seed), olive, safflower, sorghum, wheatgrass (slender)	moderately tolerant		
wildrye (Altai) wildrye (Russian)	tolerant		

Paper No. 5

THE ROLE OF SOIL CONSERVATION IN WATERSHED MANAGEMENT ON AGRICULTURAL LANDS

by

N. Gil

1. GENERAL REMARKS

1.1 Watershed management deals with all lands within the boundaries of a drainage basin. It is not only concerned with the agricultural lands at present 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 management, special attention will be given to climate, hydrology and the ecological balance of a given watershed.

1.2 The importance of these latter subjects and their influence on the inherent capabilities of the agricultural lands, their physical improvement and the return of high and sustained yields cannot be sufficiently stressed. Most damage by erosion of agricultural uplands and other damage to lowlands is created by disturbing the ecological balance of the drainage basin, destruction of its protective plant cover of trees and grasses, misuse of land not fit for cultivation and wrong agri-technical methods.

1.3 Man is the beneficiary and the destroyer of his own environment and its production capacity. The population explosion, the need to produce more and the lack of means to even maintain yields by adequate inputs, traditional restraints, lack of adequate extension and many other reasons, have created a vicious circle of population increase and diminishing resources. The result is a rapidly increasing group of sub-subsistence farmers in developing countries.

1.4 This paper will restrict itself to the role of soil conservation on agricultural land within the overall and integrated approach of comprehensive watershed development and management. But, as mentioned above, no real and complete solutions can be expected to stop deterioration of agricultural lands and to rebuild their productivity without attention to all other aspects and components of comprehensive watershed development plans.

2. CONSTRAINTS

2.1 Human factors

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 the steep hillsides which should not have been cultivated at all. Many of the present bad lands were in the past such areas converted into agricultural lands.

It is however even more difficult to prevent further deterioration on rapidly eroding land still under cultivation. Sometimes, this will be practically impossible without complete retirement from cultivation of such areas. To do so, faced with the hunger for land of an increasing rural population, may seem unrealistic. It has however not been sufficiently realized by farmers and governments, that there may be no other solution. Expansion soil conservation practices on marginal lands could - at the best - only postpone the unavoidable destruction of such lands. In fact, it would only prolong the agony of the poor farmer without solving the problem. These realities should be faced and the necessary steps be taken. It may be resettlement in other areas where arable land could still be reclaimed, or the absorption of the surplus manpower into other industries or segments of the economy. Otherwise the results will be famine, starvation and violence. Hungry people have nothing to lose and may be driven to desperate actions.

There are many aspects of human behaviour which may play their part in the reaction of the farming communities towards the requirements of proper soil conservation activities in a watershed and in agricultural lands, such as: customs, traditional constraints, social set-up within the family and the village, and others.

All this will have 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.

2.2 Physical and local constraints

A very close and interdependant relationship exists between all phases of comprehensive watershed development. Soil conservation activities 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 deserve special attention. However, without the complementary works in other sections of the watershed development plan, it may sometimes only give temporary relief, e.g. the hydrology of a watershed will depend on the conditions of all its lands. The agricultural sector will probably be only a minor factor in the overall water regions of a drainage area. This will be especially 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 will depend to a large degree on land consolidation, cooperation between farmers and other aspects which will be different in each locality. It is important to investigate and fully comprehend these prerequisites, to prevent a patchwork approach which will lead to certain failure.

3. SOIL EROSION ON AGRICULTURAL LANDS

All sloping agricultural lands are exposed to erosion if not properly managed and protected. Depending on soil-texture and structure, the grade of erosion will differ from place to place on different slopes and under different levels of management. The climatic conditions, such as rainfall distribution and intensities will play a decisive role on the above subjects and on the steps to be taken to repair and prevent damage.

Exact figures on the magnitude of erosion can be obtained from experimental plots, but even without research it is not difficult to detect erosion and estimate its severity - however without exact quantitative figures. For the trained eye it will be easy to observe splash - sheet - and rill erosion, which are often disregarded as the dangerous start of soil degradation and erosion which in fact they are. It is certainly easy to observe gully erosion. This is however already the last and most destructive face of water erosion. Conservation practices should always start in the earliest stages.

Wind erosion is difficult to measure by any means but it is a very obvious phenomenon which can be easily detected by the trained observer.

There are other aspects of soil conservation on arable lowland which are not directly connected with erosion control: raising watertables, alkalinity etc. All these subjects have to be considered in a comprehensive watershed development plan.

4. SOIL CONSERVATION ON AGRICULTURAL LANDS

4.1 General observations

Soil conservation has a wide scope, much beyond the generally accepted standards of physical works for erosion control. It is in fact a comprehensive approach to soil and farm management in which all so-called soil conservation practices contribute only a part to the overall target of maintaining and improving soil fertility, to the improved relationship between soil water and plant and to higher sustained yields. It is the most important segment of re-establishing and maintaining the ecological balance between man and nature.

Mechanical means for erosion control should be considered as supplementary measures for soil conservation on arable land and should be applied only if and when the physical conditions - slope, soil texture, rain distribution, intensity etc.- are such that good farm management alone is insufficient to prevent erosion. But, even under these conditions, soil fertility, maintained or established by good farm management should always be considered as the first slope in soil conservation on arable land. There is a tendency in most countries to divorce soil conservation and farm - (soil) - management from conservation practices. Consequently, expensive physical works are carried out without any regard to the integrated approach which could save large investments and in all cases will produce the highest benefit to the farmer. There certainly arises the question of institutional set-up and the place of soil conservation in relation to other services, most of them with a much longer tradition of existence to the rural population. In integrated watershed management these problems have to be solved before embarking on such works. The necessary co-ordination and cooperation between related services have to be a "sine qua non" for any such activity. Under the conditions prevailing in most countries, where different organizations deal with single subjects, it may however be difficult and sometimes even impossible to establish this essential integration. Soil conservation starts and ends with good soil and farm management. One without the others will certainly fail in the end. Good soils and dense plantcover may require only simple conservation methods (e.g. contour cultivation) on certain soils and under moderate topographic and climatic conditions. The same area may require much more intensive works under poor farm management and on degraded soils.

Soil conservation on arable land in the framework of watershed management may establish valuable guidelines by demonstrating the essential multidisciplinary requirements of soil conservation.

4.2 Soil conservation

4.2.1. Land use

Agricultural lands contribute in general a much higher percentage of eroded material than their area percentage of the total area in a watershed. This is due to the constant cultivation of such lands and the exposure to the forces of run-off water and wind without a protective plantcover during certain periods of land preparation, planting and after harvest. Furthermore, successful crop husbandry demands occasional or permanent weeding and cultivation of row-crops, under such conditions erosion will be accelerated compared with uncultivated lands of the same type and topography.

In watershed management all parts of the drainage basin will be treated, but special attention has to be paid to the agricultural lands, due to the above conditions. Furthermore agricultural lands provide the rural population with most of the available labour.

In general, the area of cultivated land may vary between 15-40% of the total area of a watershed, 25-30% will probably be the average figure. Even this percentage has been reached by the conversion of forest and grassland on steep slopes and shallow soils which should not have been converted at all.

Shifting cultivation which was practised during many generations and which was well adjusted to a sparse - sometimes semi nomadic-population, became gradually permanent. Even the improved systems of this practice, 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 or improve the above system which may give some temporary relief. It seems however that the time has come to abandon any hope that permanent solutions can be found to a system which worked well 160 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 to exclude this method of soil conservation from comprehensive watershed management except in very special cases of sufficient land reserves of high capabilities.

It has been pointed out that good soil management is the fast and foremost step in soil conservation on agricultural land. This implicates that only land which can be properly managed should be under cultivation. An exact land use capability survey is consequently the basis for any decision in regard to agricultural lands which are at present cultivated and should be retired, 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.

4.2.2. Coordination of soil conservation on agricultural land with the watershed management plan

In the framework of comprehensive watershed management, soil conservation measures on agricultural land have to be incorporated into the integrated development plan of a watershed. The lowlands and the bottomlands of the side valleys consist mostly of medium or large sized blocks of cultivated land. Plans for improvements will be relatively easy to prepare and to implement.

One of the main problems will be fragmentation of ownership. Soil conservation practices will have to be employed without the possibility to consider the irregular boundaries of the small plots of individual farmers. Cooperation of a whole village community or a number of villages is required to make soil conservation activities possible.

On the uplands the conditions will be different. If large upland tracts are cultivated, the same approach as on lowlands has to be applied. In many cases however the plots will be small, scattered over and intersected by side areas of uncultivated land. Land consolidation under such conditions will be much more 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 but it should be already spelled out that the treatment of each individual plot would be ineffective and that no patchwork improvement would be carried out.

Practically in all cases and on all lands cooperation of the village communities is essential. The farmers on the lowlands have to realize that the activities on the uplands for their farmers are of benefit to themselves. Without "give and take" no realistic solutions to the joint problems can be found. Upland farmers also have to realize how watershed management on the uplands, surrounding their arable land, will be of benefit to them. Both segments of the rural population in a watershed have to fully cooperate in all improvements, which will not only raise their standard of living but will also improve their general living conditions and environment. Without such cooperation watershed management cannot succeed.

4.2.3. Grouping of soil conservation activities as related to comprehensive watershed management

It is not intended to go into details on each soil conservation practice which may be applied under different soil and topographic conditions. However, considering the requirements of comprehensive development, two main groups of soil conservation practices on arable land and their part in an integrated development plan can be defined. In different climatic zones, on different soils and slopes and under varying social and economic conditions, the importance of each component in a group will change. In a general paper only passing indications can be given to these subjects.

Uplands

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

In practice, the yields of upland crops in developing countries are however 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 on lowlands. Flood (border) irrigation by gravity is mostly used and the more sophisticated methods of irrigation (sprinkler - drip irrigation) are practically non existant. Furrow irrigation can be efficiently used on uplands, provided the necessary levelling is carried out. Sprinkler and drip irrigation are well adapted to uplands. In most cases upland irrigation will require a pumplift and for sprinkler and dry irrigation additional pressure is necessary.

It is regrettable that in most countries little attention has been paid to research, extension and the supply of fertilizer, plant protection material and revolving funds for uplands. Governments and farmers have not realized the high potential of uplands. The upland farmers are therefore the poorest farmers in most developing countries.

Uplands will require very special attention in watershed management. Government services should be equal to the facilities provided to lowland crops. This is essential for the production of acceptable yields.

Soil conservation measures depend to a large degree on these latter government policies. Sometimes considerable investments have to be made to prevent further degradation of uplands. It may be beyond the farmers' ability to carry out all necessary improvements by his own labour and resources. Furthermore, all conservation activities of the upland farmer will be of benefit to the lowlands by reducing floods, sedimentation etc. This will also be of benefit to the urban population and the financial burden should also be borne by them.

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 will be seldom found in developing countries. Consequently, broad base terraces, strip cropping and similar practices will not be practical. On small plots and gentle slopes contour cultivation, contour ridges and grass strips may be more feasible, cooperation between individual farmers will be essential especially for the surplus water disposal systems, such as waterways interception and diversion ditches and for irrigation facilities. Land consolidation according to a well designed conservation plan will certainly be of the utmost importance.

On steeper slopes, where the above simple conservation practices will be insufficient to stop erosion, bench terracing will probably be the most effective practice. Here again, land consolidation will be an important factor.

Well laid-out bench terraces even on slopes of up to 35% can prevent erosion, increase water infiltration and should be considered as the most important practice 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 would be safer and no losses of land by terrace risers would occur.

Effective soil conservation on agricultural uplands is most important. These lands are a major source of erosion, run-floods and siltation. Above all these lands provide the livelihood for a large segment of the farming population.

<u>Lowlands</u>

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. Soil conservation works in these areas will be of a different nature to that on uplands. Erosion control practices will be necessary only in limited locations.

The water regime, land use and crop production will depend to a large degree on the condition of the upperparts of the watershed and the soil conservation activities carried out on all uplands-cultivated and not cultivated. Under climatic conditions which require supplementary irrigation, the watersupply from local sources will depend on the condition of the drainage basin. Consequently the cropping pattern on lowlands may undergo remarkable changes with the change of conditions in a watershed: its degradation and misuse or its improvement.

Water storage, prevention of flash floods and sedimentation in the drainage system, recharge of groundwater resources, springs, riverflow and many other benefits which will normally serve the lowland farmer, will be the results of integrated watershed management - e.g. conservation of the natural resources of a 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 will be concerned with maintaining and improving soil fertility by good farm management. This will include - in the case of irrigation - proper levelling and application of water, prevention of alkalinity and creation of swampy conditions.

Under dry-land farming the main objective will be good soil and farm management.

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

5. CONCLUSIONS

Watershed management is a multidiscipline activity. It can be simply expressed as the establishment and maintenance of the ecological balance and the equilibrium between man and his environment.

Soil conservation on agricultural land is an integral and highly important part in this undertaking.

ROLE OF COVER CROPS IN SOIL AND WATER CONSERVATION

by

B.N. Okigbo and R. Lal

1. INTRODUCTION

Erosion can be a serious problem in tropical soils, particularly if the management practices are not related to the high climatic erosivity, and high detachability of some tropical soils resulting in surface sealing and low infiltration rates. Permissible limits of soil erosion for some of the shallow tropical soils are considerably lower than for deep temperate soils with favourable rooting characteristics of the sub-soil horizon.

Considerable experimental data available from tropical regions indicate that for areas with annual erosivity index exceeding 400 foot-ton per acre, soil loss of as much as 100 t/ha/annum can occur even on gentle slopes of 3 to 5 percent. The enrichment ratio of the eroded sediments being 2 to 10 for nutrient elements such as organic matter, nitrogen, phosphorus and exchangeable cations, soil erosion can result in a rapid decline in the productivity of a minority of tropical soils. Crop yields from eroded soils are generally below the economic level of production even with heavy doses of commercial fertilizer. In short, there is no economical substitute for adequate soil and water conservation measures adopted right from the begining of land clearing and development.

A majority of the tropical farms, particularly those in south-east Asia and in tropical Africa, are below 5 hectares. Commonly recommended practices of terracing, contour farming with adequately designed and properly maintained water ways and cut drains, are neither economically feasible nor practically applicable under the socio-economic and financial resources of the small farmers. What are therefore suitable alternatives in terms of soil and water conservation measures?

The objective of this report is to describe the applicability of cover crops and mulch farming techniques for tropical soil and water management.

2. SOIL MANAGEMENT FOR EROSION CONTROL

The natural vegetation cover on tropical soils maintains a hydrological balance in which the surface runoff component of the hydrological cycle is minimum. If arable crops are substituted for the forest cover without disturbing this hydrological balance, the problem of erosion would be nonexistent or minimal. This can be achieved through the application of residue mulches on soil surface. Crop residue acts as an energy dissipator which absorbs the raindrop impact and prevents dispersal of the soil aggregates. The infiltration rate of the soil is maintained at a high level under mulch because:

i. structural porosity of the soil is maintained, there is no surface sealing and crust formation,

ii. macro-pores open to the soil surface remain intact and functional in transmitting water through the soil,

iii. biological activity of soil fauna is maintained at a level equivalent to that under natural vegetation. This activity provides additional pores for water conduction.

The potential infiltration rate of most of these soils is high, and can be maintained with even small quantities of plant residue mulches. The mulch factor for an alfisol under a simulated rainfall is shown in Fig. 1. For an half-hour storm, the runoff is 50, 20 and only 5 percent of the unmulched treatment, respectively for mulch rate of 1, 2 and 3 t/ha. For an hour storm of the same intensity, the runoff losses were 95, 25, 15, 10 and 5 ton/ha. Similar results were obtained for the sediments transported in the runoff. Field observations made on small runoff plots as well as on watersheds have confirmed these laboratory findings (Lal, 1976).

Though mulching is an effective erosion preventive technique, it may be difficult to use for large areas under arable or row crop farming. One of the practical means of obtaining mulch is through the use of no-tillage systems with appropriate herbicides to control weeds. A large number of field scale and plot studies at IITA have shown that crop yields at least equivalent to that of conventional ploughing can be obtained by this technique without additional erosion control measures (Lal, 1976).

This technique, however, can only be used for some crops with special package production including seeding technique, weed control, quantity and method of placement of fertilizer and insecticides, and proper cropping systems and rotations to ensure that there is an adequate quantity of crop residue on the soil surface.

3. ROLE OF COVER CROPS

To be very effective, special requirements for the no-tillage system are: adequate amounts of crop residue, required weed control, a minimal dependence on herbicides, built-in rotational sequences, and cropping systems to eradicate insects, other pests and pathogens. Lack of adequate quantities of plant residues on the soil surface can result in degradation of soil structure (Fig. 2). For example, the infiltration rate of soil in a plot under no-tillage system and from which crop residues had been deliberately removed declined progressively over a period of 4 years. The infiltration capacity in 3 hours was 145, 110, 75 and 75 cm for 1972, 1973, 1974 and 1975 respectively. The equilibrium infiltration rates were correspondingly low as well. Some of the rhizomatous weeds are resistant to paraquat and tend to persist in no-tillage plots over a period of time.

Reclamation or improvements in soil structure of eroded land is another important aspect of land management which needs to be included in the management system. Building up of the structural profile and organic matter content of the surface horizon of the eroded plot can be done through the use of some cover crops over a period of time (Lal et al, 1977).

Maintenance of soil structure, weed control, adequate crop residue and other requirements of the no-tillage system can be met through rotations involving suitable cover crops. A flow diagram of such a management systems is shown in Fig. 3.

4. CROP PERFORMANCE AND COVER CROPS

The results of performance of various food crops planted through a series of sod species are shown in Table 1. It is encouraging to note that crops such as maize, cowpea, pigeon peas, soybeans and even cassava can be planted and successfully grown in suppressed sod with no-tillage system of soil management. There are significant differences in crop yield as influenced by the nature of cover crop grown. In general crops grown in sod of leguminous creepers such as Stylosanthes gracilis, Centrosema pubescens and Pueraria phaseoloides yielded better than the other. These leguminous cover crops are easy to establish, provide a quick ground cover, can be easily suppressed by either chemical or mechanical means and their stems in the residue are not very woody and thus provide a manageable cover to seed through. In addition, the yield of crops planted through these cover crops are at least equal to that under conventional system.

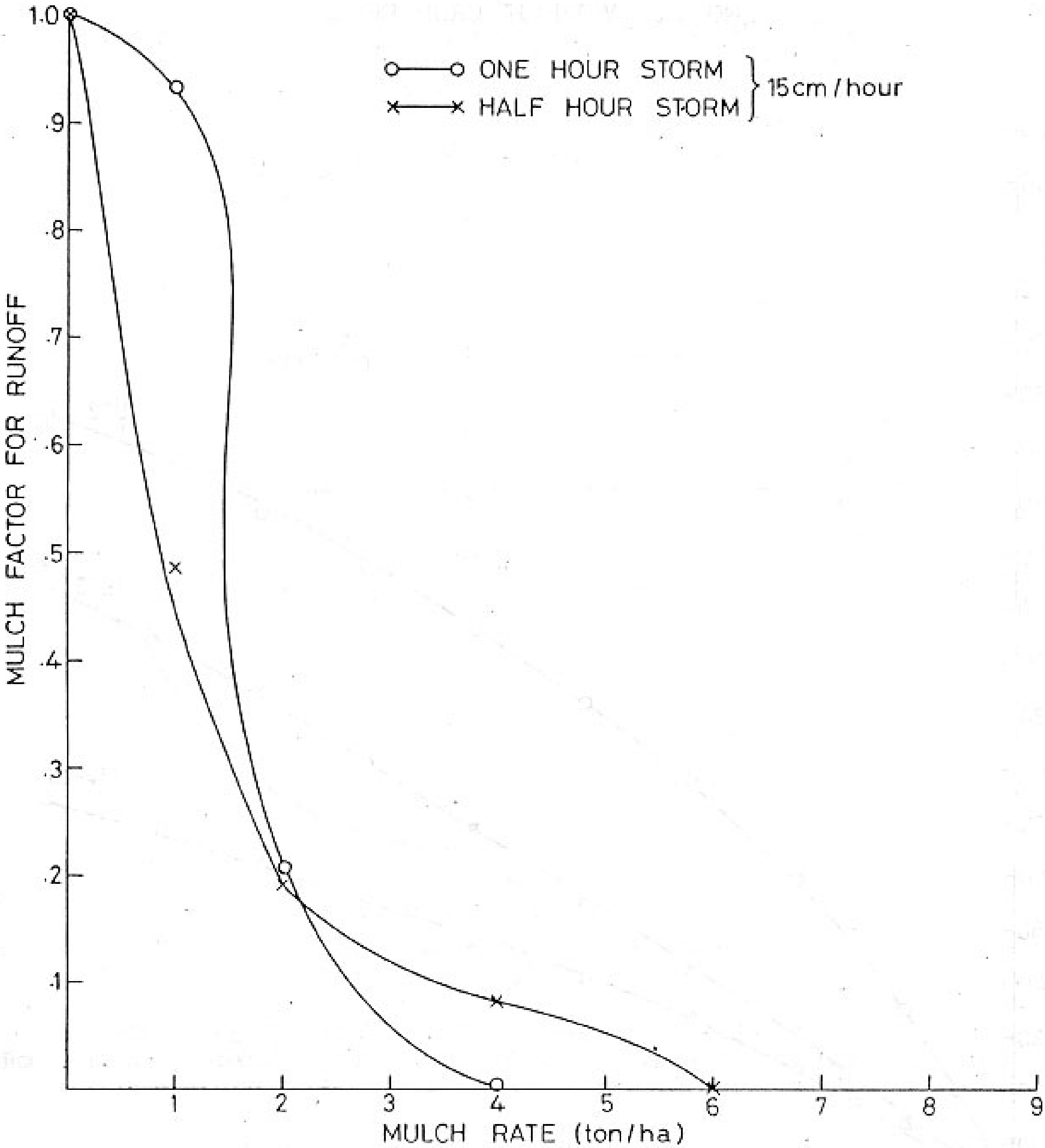


Fig. 1 Effect of mulch rate on runoff from simulated rainstorm

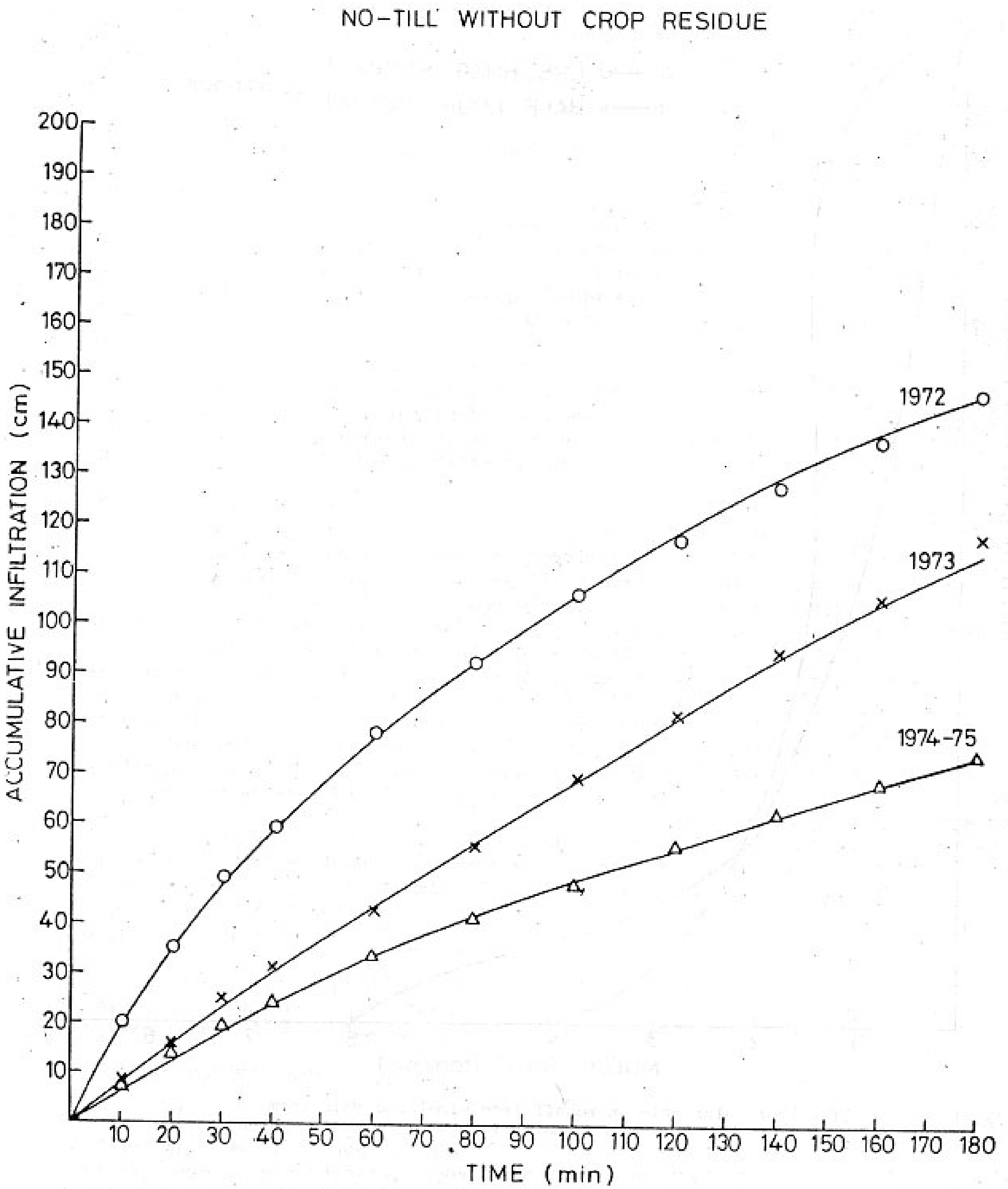
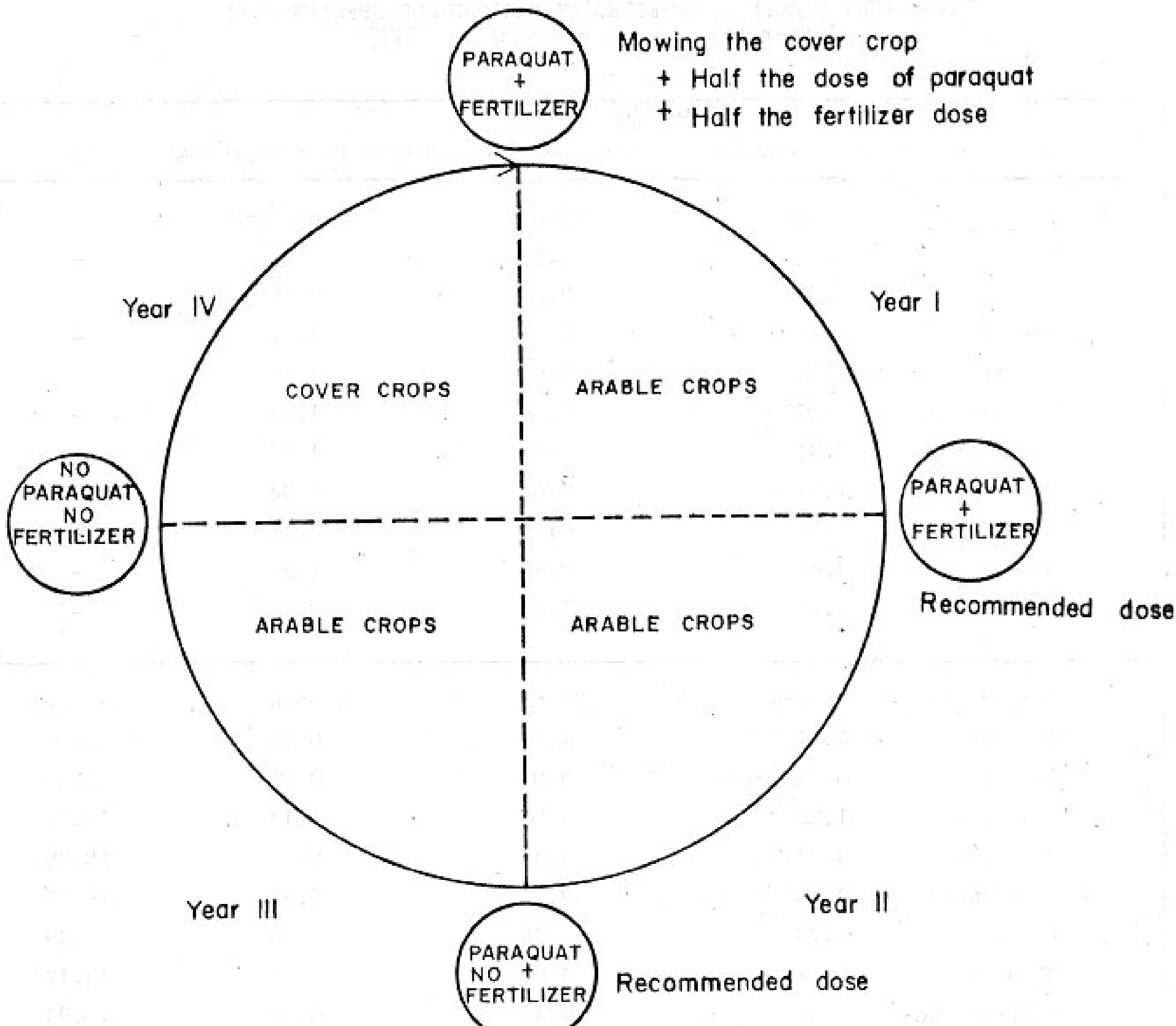


Fig. 2 Influence of lack of mulch (crop residue) on deterioration of infiltration rate with no tillage



FOUR YEAR ROTATION FOR ARABLE CROPS

Rotation I : Maize followed by cowpeas, maize–soybeans, maize inter or relay planted with cassava, cover crop

Rotation II : Maize– cowpeas or soybeans, pigeon peas–sorghum, or inter planted with cassava, cover crop

Table 1 GRAIN YIELD (t/ha) AS AFFECTED BY VARIOUS SOD SPECIES 1974
(After Lal, Wilson and Okigbo, 1977)

		CROPPING SEQUENCES			
		Maize-Cowpeas	Cowpea-Maize	Pigeon peas-Soybeans	Cassava
(a)	First Season	Maize	Cowpea	Pigeon pea	
	Panicum	3.13	0.37	1.19	-
	Setaria	5.77	0.49	0.86	-
	Brachiaria	5.17	0.76	1.27	-
	Melinis	5.18	0.63	1.19	-
	Centrosema	5.79	0.76	1.23	-
	Pueraria	4.77	0.84	1.12	-
	Glycine	5.05	0.65	1.04	-
	Stylosanthes	5.17	0.61	1.17	-
	Ploughed	4.87	0.50	1.06	-
	LSD (.05)	2.21	0.05	0.20	-
(b)	Second Season	Cowpea	Maize	Soybean	Cassava
	Panicum	0.62	1.69	0.50	3.50
	Setaria	0.71	2.97	0.91	7.90
	Brachiaria	1.04	3.80	1.14	17.39
	Melinis	0.87	3.43	0.77	18.85
	Centrosema	0.76	3.73	0.75	15.01
	Pueraria	0.79	3.44	0.80	19.49
	Glycine	0.71	3.02	0.93	14.12
	Stylosanthes	9.67	3.11	0.91	19.83
	Ploughed	0.43	2.06	0.51	8.05
	LSD (.05)	0.06	0.53	0.23	2.53

The potentialities of some legumes being grown as live mulch (i.e. living cover) through which crops such as maize, rice, cowpeas, and soybeans are drilled without cultivation or killing of the legumes are receiving preliminary evaluation at IITA. Under such conditions the legume may contribute some nitrogen to the soil and with the applications of adequate amounts of phosphorus and potassium and reduced levels of nitrogen, maize planted through Desmodium triflorum gave 2.38 t/ha as compared to 2.23 t/ha on ordinary maize stover residue mulch and rice gave 4.12 t/ha on live mulch as compared to 3.41 t/ha on rice straw mulch (Wijewardene, 1976). Preliminary observations indicate that water requirements of both the legume live mulch and the companion non-legume crop may be different and perhaps higher than under sole crop conditions.

5. ROLE OF SOME PROMISING COVER CROPS IN SOIL AND WATER CONSERVATION IN THE TROPICS

Cover crops have long been used in soil conservation and in soil fertility maintenance as green manures. Cover crops especially leguminous species have the following advantages in tropical agriculture (Bunting & Milsum 1928; Whyte & Trumble 1953; Wingley 1929; Webster and Wilson 1966):

a. Control of soil erosion by affording effective cover of the soil and minimizing the pounding action of the rain;

b. reduce the undesirable effects of heat or sunshine by reducing temperature fluctuations;

c. ensure that adequate levels of organic matter are maintained;

d. improve soil structure, aeration and texture while reducing leaching, and encouraging more infiltration and water holding capacity than on bare soil;

e. deep rooted cover crops are able to bring to the surface mineral nutrients which become available to the crop;

f. leguminous cover crops may significantly contribute nitrogen to the soil;

g. may compete effectively with or surpress obnoxious weeds;

h. sometimes control plant diseases and pests.

Disadvantages of cover crops include (a) competition with associated crops for water and nutrients, (b) sometimes harbouring pests and diseases although some may also supress nematodes, and (c) climbing of vigorous twiners on permanent crops and often damaging the crop by obstructing translocation.

Leguminous crops that have been found suitable as cover crops in plantations and in soil conservation include Calopogonium mucunoides, Centrosema pubescens, Indigofera spicata, Pueraria phaseoloides, Stylosanthes gracilis, Dolichos hosei Glycine javanica, etc. (Bunting & Milsum, 1928; Crowder, 1970-71; Whyte & Trumble 1956; Wingley, 1969; Webster & Wilson 1969; Williams 1967; and Pursglove, 1969). Many of these tropical cover crops have also been found to be suitable forage crops alone or in mixtures with legumes (McIlroy, 1969; Wrigley, 1969).

Widespread use has been made of cover crops in tree crop plantation culture. At IITA studies are currently devoted to the use of cover crops in zero or minimum tillage technique of arable crop production. This involves the use of cover crops in one to two year fallows after which they are killed with herbicides and arable crops such as maize, cassava, soybeans, cowpeas and pigeon peas are sown through the dead residue by hand, hand operated drills or mechanical planters. Alternatively, the cover crop may be moved or killed along the rows in which the crops are planted. Another method involves the use of selected covers as living or live mulch through which crops are planted with hand operated or mechanical planters without killing all the legume and only by disturbing the soil and/or killing the legume cover along the rows. Cover crops which have been used as fallow crops and killed with herbicides in zero tillage studies at IITA include Centrosema pubescens, Pueraria phaseoloides, Stylosanthes gracilis, Psophocarpus palustris, Stizolobium deeringianun and some grasses such as Brachiaria ruziziensis, Cynodon nlemphuensis and Paspalum notatum. Leguminous covers which have been used in preliminary live mulch experiments are Arachis prostrata and Desmodium triflorum while Indigofera spicata has shown some promise.

A brief description of these legumes based on studies reported by various authors (Bunting and Milsum, 1928; Hutchinson, Dalziel and Keay, 1958; Hewitt, 1969; Wrigley, 1969; Whyte Nilsson-Lessner and Trumble, 1953) is given below.

Arachis prostrata

A prostrate dwarf perennial with glabrous trifoliolate leaves, yellow flowers, and rhizomatous long creeping stems very much resembling the cultivated groundnut. When properly established it effectively suppresses weed growth and is somewhat adapted to acid soils but is only slightly drought resistant. It roots along the stem especially at the nodes and is propagated by stem cuttings. Arachis prostrata is a native of South America but has been introduced into many parts of the tropics. At IITA preliminary studies indicate that it is a potential live mulch legume which has been compatibly grown with maize, cowpeas and rice. Whyte, Nilsson-Lessner and Trumble (1953) report that it is also a good forage legume which grows well in mixtures with Paspalum notatum.

Centrosema pubescens

A vigorous or aggressive trailing or creeping perennial legume which forms good ground cover but has a tendency of twining and climbing on erect shrubs, trees or posts with which it may be in contact. The stems and trifoliolate leaves are softly pubescent, stipules are minute, flowers mauve in colour with purple lines or white with purple markings and pods are up to 6 cm long with 10 - 15 seeds which are brownish with dark green mottles.

Centrosema is drought resistant, grows well on a range of soils especially in well drained soils under wet conditions but does not stand prolonged flooding or swampy conditions. It is also somewhat tolerant to acid soils. Centrosema is easily established by seed at the rate of 3-4 kg per hectare. There are about 38 000 seeds per kilo of Centrosema seed. For good and uniform germination, mechanical or acid scarification is necessary. Centrosema is difficult to mow but re-generates easily. At IITA it has been found to be a suitable cover crop in minimum or zero tillage in which the legume is killed with paraquat after 1-2 years and prior to crop establishment.

Desmodium triflorum

A small prostrate much-branched creeper forming dense mats. The prostrate more or less pilose stems with trifolialate finely appressed leaves which are pilose beneath, and about 1 cm long form very good ground cover. The purple or pink flowers are borne 1-3 terminally or in the axils of stipulate pinnately trifoliolate leaves. Pods are 5 seeded and indented on one side. Sometimes it constitutes a weed in lawns and is adapted to dry and wet well-drained soils of the tropics.

Demodium has been used as a cover crop in rubber plantations in Malaya where it was reported to persist even in old rubber plantations. It has also been reported to produce good fodder in hot climates (Whyte, Nilsson-Lessner and Trumble 1953). At IITA it has been used successfully as live mulch and grows compatibly with maize, cowpeas and rice under optimum soil moisture conditions. Although it seeds well, harvesting is difficult and germination is poor. It is easily established vegetatively by stem cuttings but it does not effectively compete with many of the vigorous more robust weeds such as Talinum triangulare except after 3 to 4 weedings following transplanting.

Indigofera spicata (Trailing indigo)

A prostrate creeping perennial herb with woody older stems which spread horizontally close to the ground and develop tiny roots along the older stems. The stems and pinnately compound leaves consist of leaflets less than 3 cm long and somewhat glabrous. The flowers are orange red in colour and pods are borne in axillary spikes each with over 40 pods each bearing 8-15 seeds. Indigofera spicata is pantropic and adapted to a wide range of well drained highly weathered acid soils in areas of 1 250-2 500 mm annual rainfall. It is reasonably drought resistant and resumes growth with the onset of the rains. Although it is known to be toxic to stock, some cultivars are grown for forage.

Indigofera spicata seeds profusely and is easily propagated by seed. When planted at distances of 0.5 to 1 m apart it provides a good cover within 4-6 months. Seed rate is 1-2 kilos per hectare with each kilo of seed containing up to 500 000 seeds.

At IITA evaluation of Indigofera spicata for live mulch has just been initiated. It appears to be suitable for cover crop to be killed with herbicide for minimum or zero tillage production of arable crops.

Peuraria phaseoloides

A prostrate vigorous trailing and twining perennial herb forming a dense mat The stems which may attain lengths of up to 6-7 m and leaves are densely pubescent. The trofoliolate leaves may be up to 13.5 m long and 6 cm wide. Flowers are in racemes and are mauve in colour. Pods are narrow and smooth producing small seeds 100 000 of which weigh about a kilo.

Peuraria is adapted to a wide range of soils but does not do well in dry sandy soils. It is tolerant to soil acidity and can also tolerate slight waterlogging. It performs best in areas of over 1 250 mm annual rainfall. It does not seed heavily and seeds are difficult to harvest but it can be grown by stem cuttings (Bunting and Milsum, 1928). It has been extensively used as a cover crop in plantations all over the tropics and as a forage legume. Peuraria has been found useful in minimum tillage as a mulch after killing with herbicide at IITA. As live mulch killed with herbicides along the rows Peuraria usually climbs and strangles the associated crop as has also been observed with Psophocarpus palustris, Centrosema pubescens and Stizolobium deeringianum.

Psophocarpus palustris

This is a vigorous prostrate or twining perennial very much resembling the cultivated winged bean. It readily forms a thick cover. The leaves are trifoliate and both leaves and stems are glabrous. Psophocarpus does not root along the stems. The flowers are blue in colour. Its seeds are large and covered with velvety hairs. They do not germinate readily without scarification. Regeneration takes place readily by means of dormant seeds or tuberous root-stocks. After germination it forms a thick cover faster than any other legume tried at IITA.

At IITA, Psophocarpus has proved to be good in minimum tillage plantings of maize, cowpea, soybean, and cassava, but where it is only partially killed by moving and/or herbicide application or used as live mulch, it has a major disadvantage of climbing and almost strangling the crop.

Stylosanthes gracilis

An erect vigorous shrubby perennial popular pasture legume rarely exceeding 1.5 metres high. It is adapted to a wide range of conditions and is tolerant to acid poorly drained soil. Stylosanthes is slow to establish but is persistant, drought resistant and performs well in areas of wet and dry tropics with rainfall ranging from 900 - 2500 mm per annum. The leaves and stems of Stylo are pubescent, the stems tend to get woody with age and root at the nodes. Wrigley (1969) reports Stylo to be tolerant to hormone herbicides. Flowering in Stylo in Southern Nigeria is restricted to about three months in the year and the seeds mature unevenly and shatter if not promptly harvested. Seed rate of Stylo is about 0.8 to 1.6 kg per hectare with 1 kg of seed containing 3-4 million seeds. Once planted, Stylo reseeds itself after removal of the cover mechanically or by burning.

Stylosanthes forms good cover alone or with some grasses. In minimum tillage a cover of Stylo totally killed with paraquat supported good crops of maize, pigeon pea, soybeans and cassava. The thickness of Stylo cover renders it somewhat unsuitable for use as live mulch.

Styzolobium deeringianum (Mucuna pruriens var. utilis)- Velvet bean

A vigorous somewhat semiperennial climbing or twining legume with large trifoliate leaves consisting of large ovate leaflets. The white to dark purple flowers are in long pendant clusters. Pods are often covered with dense white or grey hairs with each pod 5-15 cm long bearing 3-6 seeds which are edible.

Velvet bean is adapted to most soils and is extensively used as a green manure and cover crop. It is easily established by seeds which are difficult to harvest. It has been used as a cover crop in minimum tillage work at IITA with good results but it is not as good in this regard as either Pueraria or Centrosema.

Non-leguminous Covers

At IITA, a number of graminaceous cover crops were compared with legumes either by killing with paraquat and sown with test crops or treated only along the row and used as live mulch. The grasses tried included Brachiaria ruziziensis, Melinis minutiflora, Cynodon plemfuensis and Paspalum notatum. None of these were suitable as live mulch and as cover crops for minimum tillage because of their persistence and tendency to compete seriously with crops planted through them. It requires more than one herbicide (e.g. Paraquat) treatment or special herbicides to completely kill them prior to establishment of arable crops.

Efforts are now directed towards evaluation of more legumes species and two grasses (Paspalum notatum and Axonopus compressus) as cover crops for live mulch in zero tillage cultivation.

Interplanting of Grain Legumes with Food crops

Cultivars of the cowpea (Vigna unguiculata), Lima beans and Vigna radiata var. aureus and other legumes are sometimes interplanted with non-legumes and both are harvested for food. Legumes may be relay planted with the non-legumes which are harvested first and the legumes companion crops may serve as cover crops and/or green manure crops. Trials at University of Ife farm, Ibadan, showed that cowpea, green gram, lima beans, soybeans, velvet bean, calopo and stylo intercropped with maize reduced maize yields as compared to maize grown alone (Crowder, 1970-71). Climbers caused up to 50% reduction in maize yield. When cowpea, green gram and calopo were planted on same rows with maize, no effect on yield of maize or legume was observed. Intercropping of legumes with maize increased grain yields during 3rd and 4th cropping seasons of two crops of maize per year as compared to unfertilized plots. Grain yields of legumes were considerably higher when they were grown alone as compared to intercropping in which the legumes compete for water (except in forest areas with sufficient rainfall), light and nutrients. On the intercropping of creeping legumes and non-legumes with starchy staples such as maize and cassava - a widespread practice in traditional cropping systems of tropical Africa - the legume or non-legume cover serves the purpose of conserving soils as well as source of food. Unfortunately, research on such cropping systems is only beginning to receive the deserved attention.

CONCLUSIONS

Mulching is an important element in minimum or zero tillage farming which promises to effectively minimise erosion, loss of organic matter and soil fertility and improve soil structure and water infiltration thereby enhancing continuous cultivation in the humid tropics with much reduced or without periods of fallow. Verv small quantities of mulch have pronouced effects in the reduction of surface runoff and erosion. However, the availability of sufficient amounts of organic residues on the soil surface, under hot humid conditions, with its high decomposition rates, may constitute a major constraint in the successful use of minimum or zero tillage techniques in the humid tropics. The use of leguminous cover crops which are killed with herbicides one or two years after establishment as mulch in zero tillage cultivation of maize, cassava, cowpea, soybeans and pigeon peas has proved successful in reducing erosion, conserving moisture and maintaining adequate levels of organic matter while giving as good or better yields than conventional tillage. The use of some creeping legumes as live mulch also holds some promise and its potentialities are being evaluated at IITA. Much remains to be done in (a) evaluation and selection of leguminous covers as sources of dead mulch in minimum tillage; (b) selection of species and evaluation of low growing leguminous or other species of covers as live mulch which can grow compatibly with selected crops; (c) development of soil and crop management techniques associated with the use of cover crops in minimum or zero tillage; (d) determination of the frequencies and minimum periods of cover crop fallows for different soils, topographic situations and ecological zones in the tropics; (e) selection of species and development of legume cover crop management systems that enhance the full realization of nitrogen fixing potentialities of legumes in minimum tillage cultivation in the tropics; (f) study of the economics of different cover crop and zero tillage/rotation/management systems for the production of important crops of the tropics; (g) development of low input equipment, herbicide or other treatments for use by small farmers in the zero tillage planting; and (h) explore the possibilities of using leguminous forage cover crops alone or in mixtures in rotations involving alternate husbandry in mixed farming systems for the humid tropics.

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Paper No. 7

STUDYING PATTERNS OF SOIL EROSION IN KENYA

by

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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 unanalysed 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 unanalysed for long periods of time. Developing countries cannot afford this waste, and the field scientist must be encouraged to analyse 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 condi-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 (Battawar 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 1948-68, 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 19 520 $t/km^2/year$. 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, 1973). 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 reationship between sediment yield and climate. Wilson, who analysed 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.

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 = 0.038 $\text{Runoff}^{1.41}$	$r = 0.73$, $n = 39$
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.

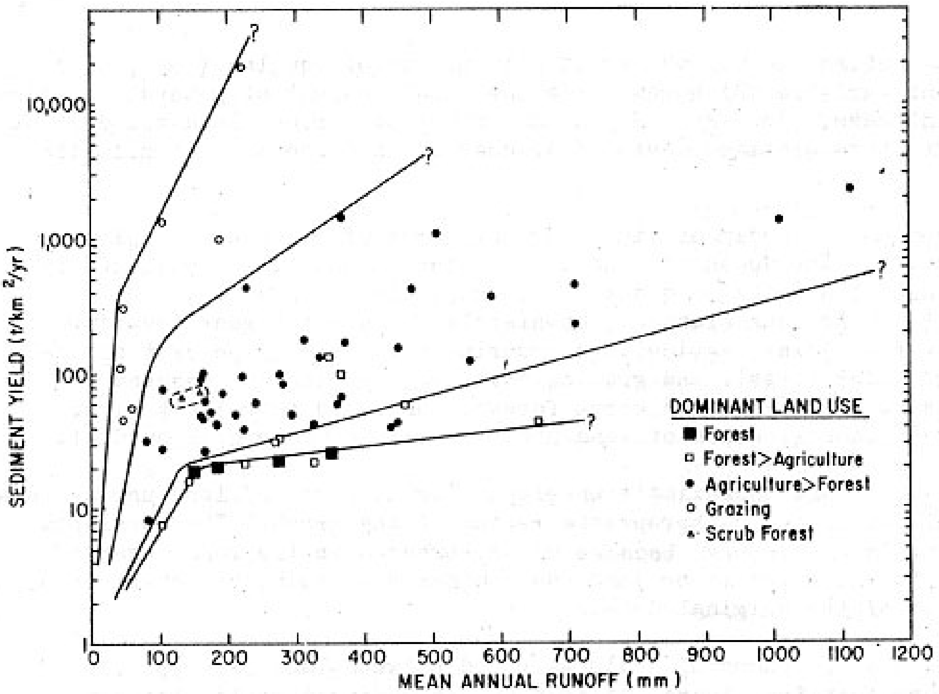

Fig. 1
Mean annual yield of suspended sediment and mean annual runoff for catchments under five dominant types of land use

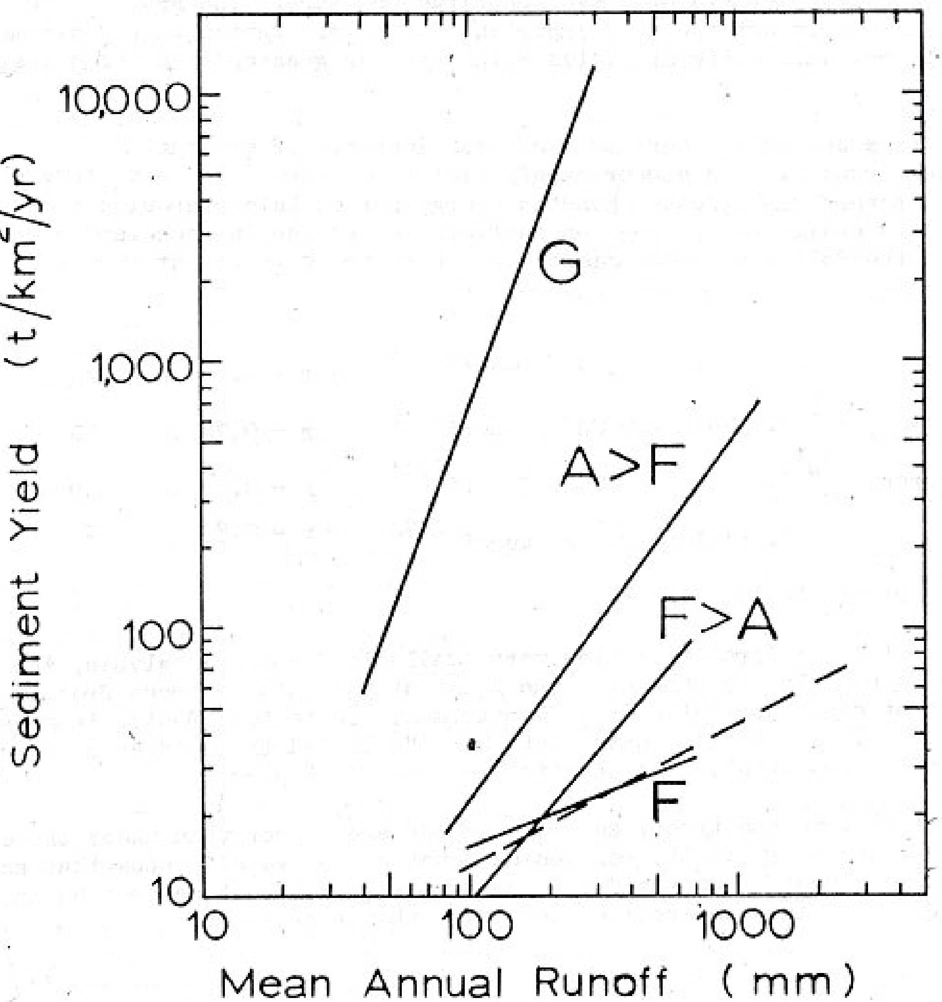

Fig. 2 Comparison of the regression lines computed for the relationship between sediment yield and mean annual runoff for each land use type. The dashed line was computed by Douglas (1967) for forest catchments in eastern Australia

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 dateable reference. Judson (1968) 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

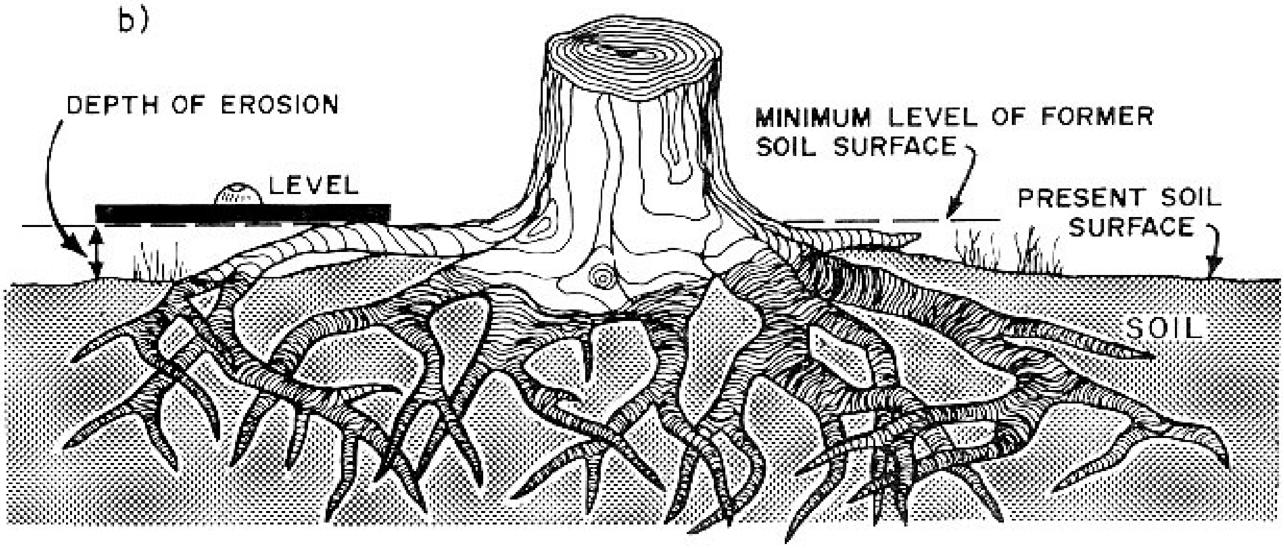

Fig. 4 Measurements of erosion rates from tree root exposures. On suitable tree species the height of the former ground surface is located by examining the tree for signs such as the position of the basal flare or the boundary between trunk bark and root bark. This should be done only after examining 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 dateable 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,

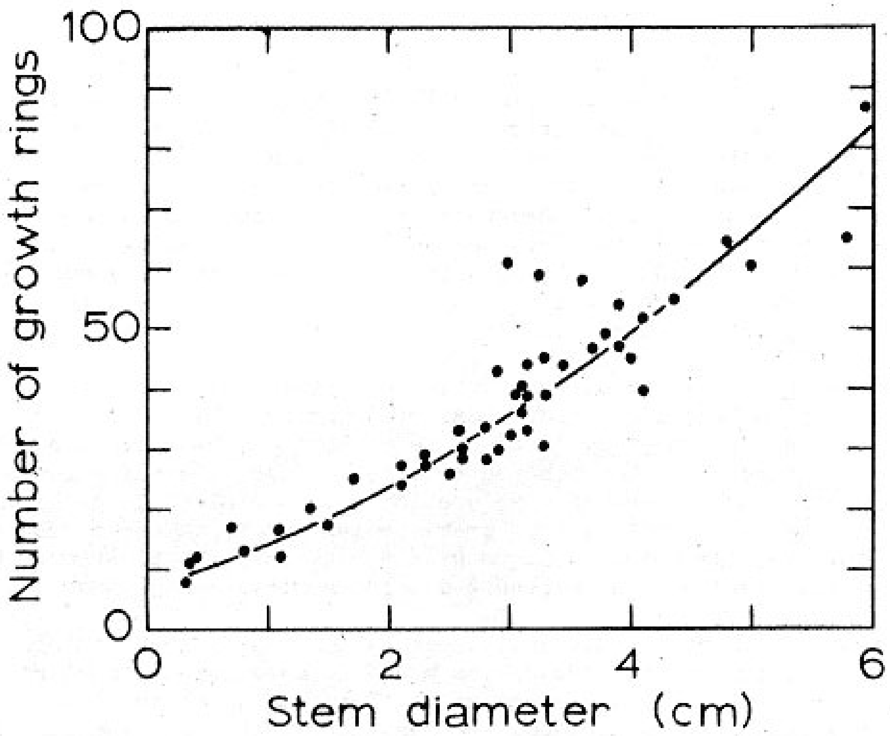

Fig. 5 Relationship between number of seasonal growth rings and trunk diameter 0.25 m above the ground surface for _Acacia drepanolobium_ trees on the Athi-Kapiti plains of Kenya. The rings have not yet been counted under a microscope and so their numbers are still tentative. Biologists measuring plant growth in the region tell us that there are two strong growth periods in each year, even during times of low rainfall

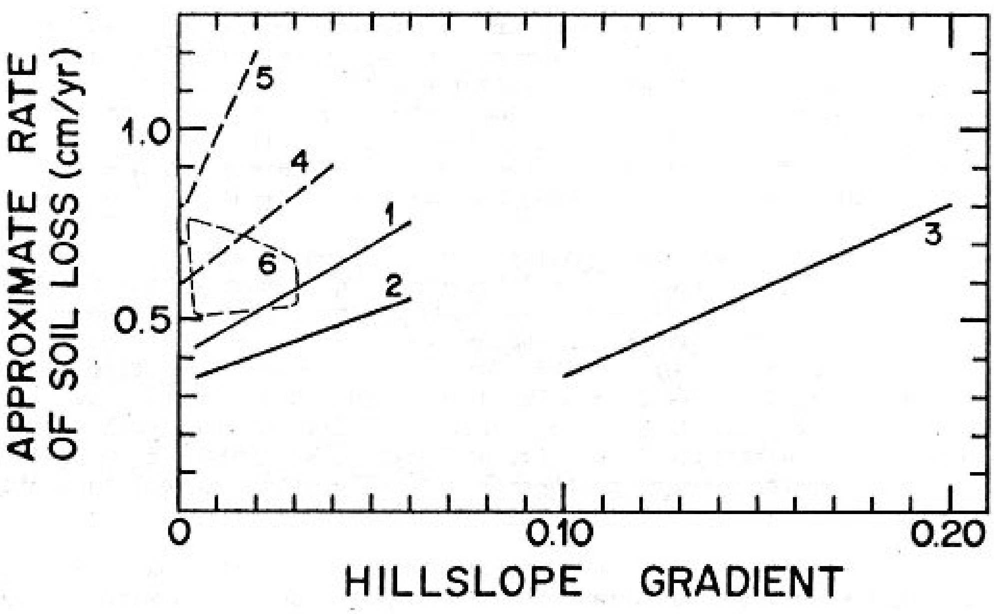

Fig. 7 Average annual rate of soil loss as a function of gradient for hill-sides on two rock types near Baringo and Maralal, N. Kenya. The granitic and gneissic Basement rocks (solid lines) weather to sandier soils than those which develop on the lavas (dashed lines). The former are more resistant than the latter to erosion

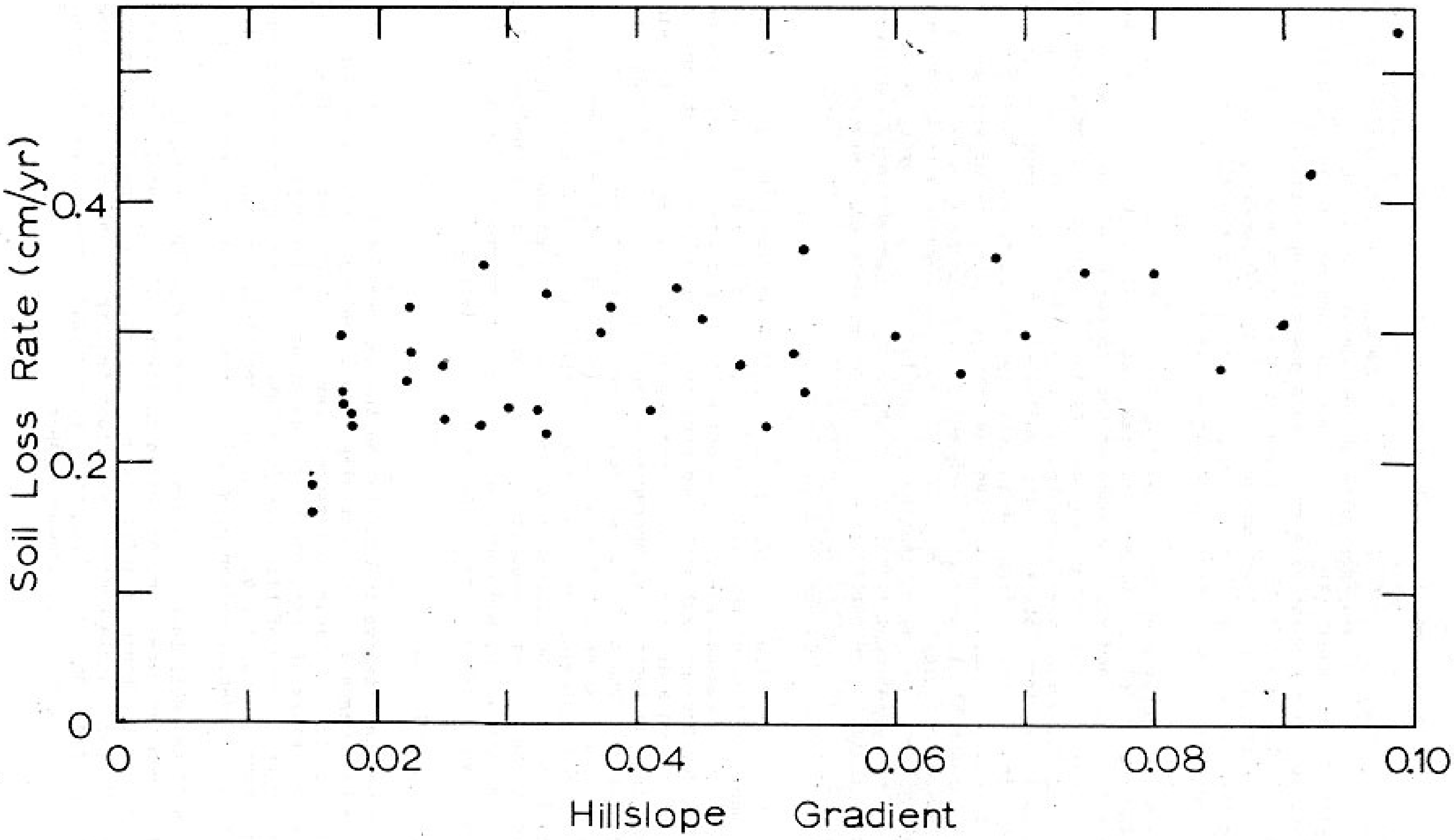

Fig. 6 Average annual rates of soil loss as a function of gradient for 38 sites on 7 grazed hillsides on the Athi-Kapiti plains of Kenya. The rates are tentative until the tree rings from which they were calculated can be checked under a high-powered microscope

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 $t/km^2/yr$ at 100 km^2 and of 90–1 620 $t/km^2/year$ at 2 000 km^2. 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.

4. CONTROLLED PLOT EXPERIMENTS

To provide quantitative information on the controls 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.

But 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.

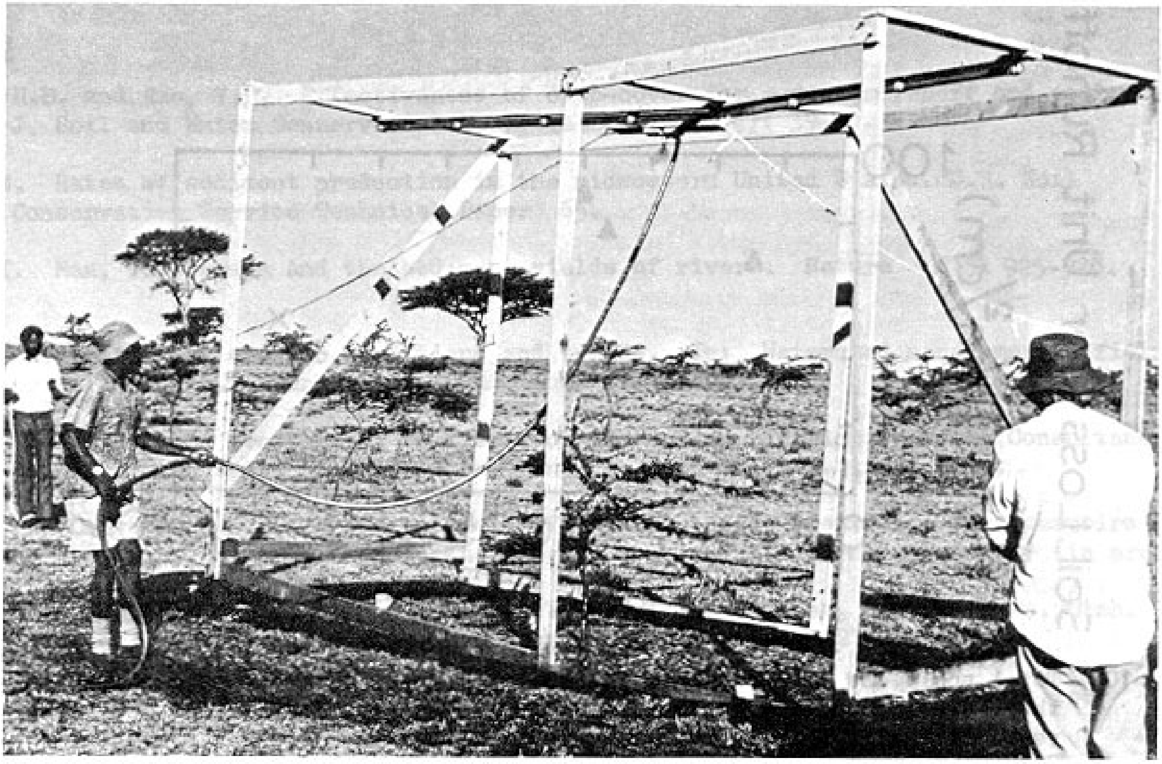

Fig. 8 The sprinkler system used for generating artificial rainstorms on hillside plots in Kajiado District, Kenya

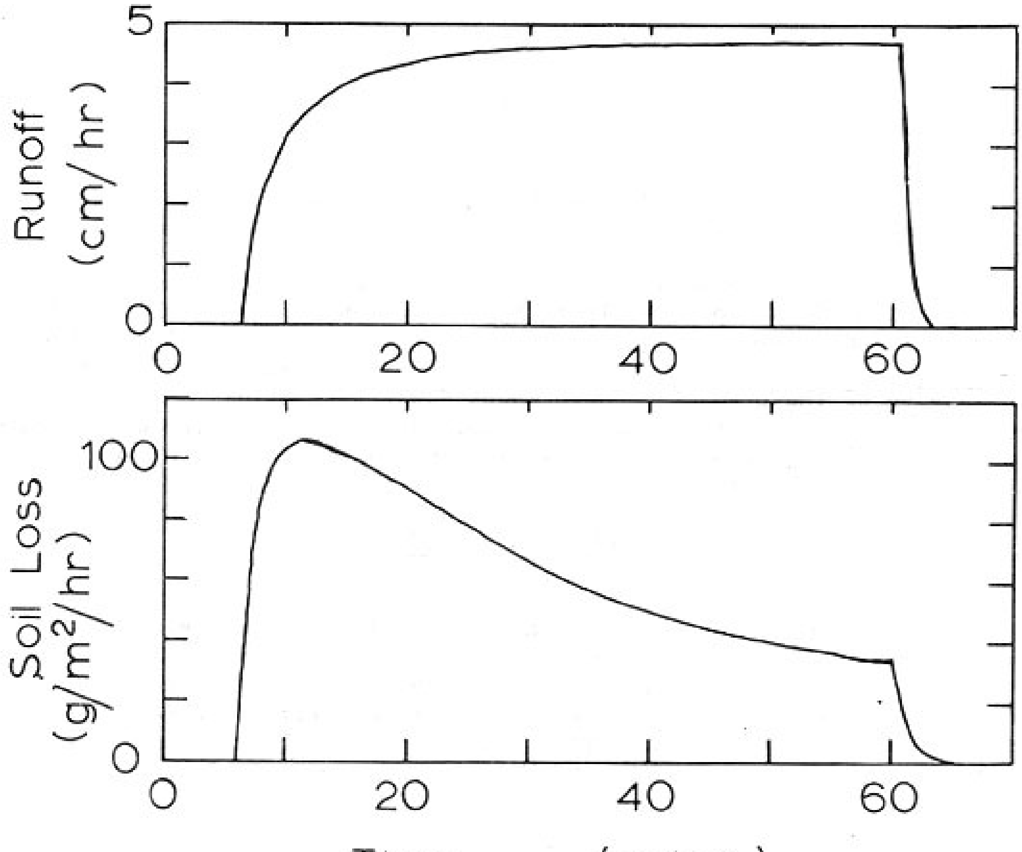

Fig. 9 Hydrographs of runoff and soil loss from a 5m x 2m plot during an artificial rainstorm. Storm duration was one hour and the intensity was 6.9 cm/hr

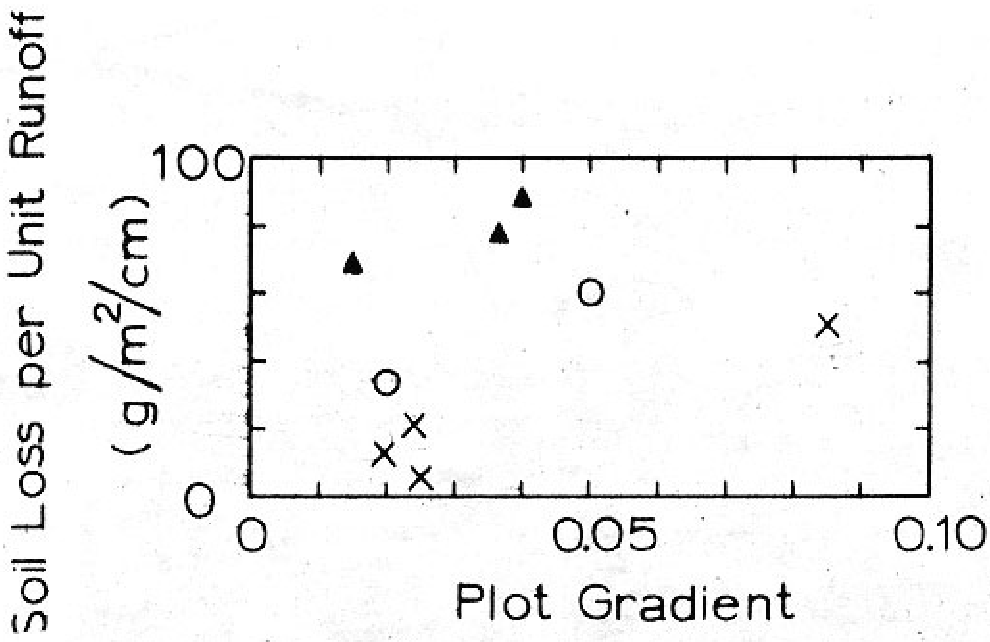

Fig. 10 Total soil loss in a one-hour rainstorm on dry conditions from plots in their usual condition at the end of a dry season. The crosses represent vertisolic clay soils on volcanic rooks with a ground cover averaging 65 - 85%; the circles represent sandy clay loams on schists with a ground cover 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.

ACKNOWLEDGMENTS

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Paper No. 8

SOIL EROSION AND RESERVOIR SEDIMENTATION - CASE STUDIES IN TANZANIA

by

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1. INTRODUCTION

Soil erosion and soil conservation have long been major issues in a number of tropical areas, not least in Tanzania. Much of the debate on these issues has been carried on with only superficial specific information on the types of processes at work, their relative importance and their rates of operation. The main purpose of our project was to obtain reliable information on the types, extent and contemporary rates of soil erosion and reservoir sedimentation in Tanzania. It was hoped that such information might form a more rational basis for future schemes of soil and water conservation in critical areas in Tanzania and other countries with similar ecological conditions.

The Dar es Salaam/Uppsala Universities Soil Erosion Research Project (DUSER Project) was carried out during the period 1968-1972.

It resulted from cooperation between the Department of Physical Geography of the University of Uppsala, Sweden, and the Department of Geography, the Bureau of Resource Assessment and Land Use Planning (BRALUP), and the Department of Agricultural Chemistry of the University of Dar es Salaam, Tanzania.

The main sponsor of the DUSER Project was the Bank of Sweden, Stockholm. The University of Dar es Salaam provided funds through BRALUP. Other valuable assistance was provided by the Tanzania Ministry of Water Development and Power and the Ministry of Agriculture and Cooperatives. The Swedish International Development Agency (SIDA) made grants towards the costs of aerial survey and part of the costs of publishing.

A first step toward rational and ecologically sound land use, in Africa or elsewhere, is to make an inventory of the types and extent of present degradation of vegetation and soil and to monitor the changes. This is true with regard to both traditional and mechanized or "modernized" forms of land use. A second step is interdisciplinary ecological research and training for better land use.

In order to study types of soil erosion, monitor present rates of erosion and determine the consequences of erosion, it is necessary to carry out continuous studies of water and sediment flow in natural watersheds. This is called the "catchment approach" or "watershed approach". Such studies must be performed in a variety of environments. So far, only a few quantitative catchment studies of this kind have been performed in developing countries. Examples of such studies are those undertaken by Dormann, Likens and Eaton (1) in New England, Douglas (2) in Malaysia, and Rapp _et al_ (3,4) in Tanzania. Some aspects of the latter studies will be presented below.

2. SOIL EROSION AND ITS EFFECTS

The most common forms of soil erosion are caused by running water or by wind, or by a combination of these two. Both water erosion and wind erosion are particularly effective in climates where long-lasting dry seasons weaken the vegetation cover and the soil is exposed to later attack by intensive rainstorms or dust storms. Vegetation cover is the best general protection against the washing away of soil particles by runoff or the blowing away of soil as dust. A dense grass cover can in this respect be as efficient as a forest cover in protecting the soil (5). Fire and overgrazing contribute very much to the erosion hazard in African semi-arid areas by exposing the soil to the assault of water and wind as well as to the heat of direct sunlight, reducting the biological activity in the near-surface zone of the soil.

Tropical and subtropical semi-arid areas are thus, in general, zones of great potential erosion hazard, due to the combination of sparse vegetation at the end of the dry season and periodically very intense rainstorms or dust storms. Other environments with potentially great erosion hazards are mountains. Many mountain areas in Africa have been subjected to a high degree of exploitation by man, with deforestation, burning, cultivation of steep slopes, soil erosion by slope wash, landsliding and other forms of degradation.

Also in the lowland, humid tropics soil degradation by erosion is a serious problem, which has been emphsized recently by, e.g., Greenland and Lal (1975) (6).

Erosion causes losses of productive topsoil, organic matter, nutrients and water. Up to 50 percent of the annual rainfall can be lost from eroded slopes due to decreased infiltration and high surface runoff. The downstream effects of this are increasing floodpeaks with higher sediment loads from denuded source areas of rivers. The increasing sediment loads result in faster filling of reservoirs and thus shorten the useful life of these reservoirs.

3. FORMS OF EROSION

The water erosion on a naked, soil-covered slope increases with intensity of rainfall, slope gradient, length of slope, surface runoff, and erodibility of the soil. Splash erosion, caused by the direct impact of water drops on the soil, affects the entire slope, from the crest to the valley botton. The splash makes the fine soil particles start moving. It also creates a wet crust on the soil; small splashed particles of soil enter and seal the surface pores, thus decreasing the infiltration rate of the water into the soil and increasing the surface runoff.

Sheet erosion is the washing away of a thin surface layer of soil. Rill erosion causes erosion furrows of several cm in depth. Gully erosion creates furrows of more than one meter in depth. All these forms of erosion can be created by temporarily high surface runoff. River erosion, either by bank cutting or bed scouring, does not come under the heading of soil erosion (interfluvial erosion), but is nevertheless of very great importance and is closely linked with soil erosion.

On hillslopes of some steepness, landslide erosion may occur, generally as a sudden movement of soil and weathered rock, creating a slide scar. Some landslide masses that begin with a sliding movement change into viscous flows as they move down the slope. Such flowing masses of loose material composed of soil or rock debris are called debris flows or mudflows (7).

The common forms of splash, sheet and rill erosion can be studied in erosion plots of a few meters in dimension or even in a laboratory. The larger forms of erosion such as gullies, landslides and debris flows have to be studied mainly in natural catchments, due to their less frequent occurrence and large size. Water erosion and slides have downstream effects on sediment transport and deposition. Thus a catchment basin is a useful unit for studies of the erosion/sedimentation system.

4. EROSION AND SEDIMENTATION IN FIVE CATCHMENTS IN SEMI-ARID TANZANIA

Man-made and natural lakes act as sediment traps and store part of the material eroded and transported by running water from the catchment. In semi-arid areas, streams flow only occasionally and the flow of water and sediment is difficult to measure. However, the sediment trapped and deposited on the bottom of a reservoir can be measured and analysed and can thus reveal the history of sedimentation since the time of the dam construction. It can also tell the history of erosion in the catchment, although only in a generalized way, as much of the material eroded from the slopes of the catchment is temporarily deposited upstream of the reservoir, e.g. some parts are deposited at the base of the eroded slope, other portions on the floodplains and still others on the riverbeds. But some material reaches the reservoir and is deposited in a delta or as fine-grained bottom sediment on the lake floor beyond the delta. Some of the fine-grained suspended material is carried out of the reservoir by the flow.

Sediment surveys of silting reservoirs can be used to forecast how fast the basins will be filled up and made useless.

The sediment-survey approach was used in studies of five small reservoirs and catchments, four in the Dodoma area (4) of central Tanzania and another near Arusha in northern Tanzania (8). The Dodoma area is a semi-arid plain with scattered hills of granites and gneisses, so-called inselbergs (Figure 1). The soils are red and sandy on the gently sloping plains (= pediment slopes), and black, cracking clays on the flood-plains. The annual rainfall is less than 600 mm. The dry season is about 7-8 months long, lasting from May until December.

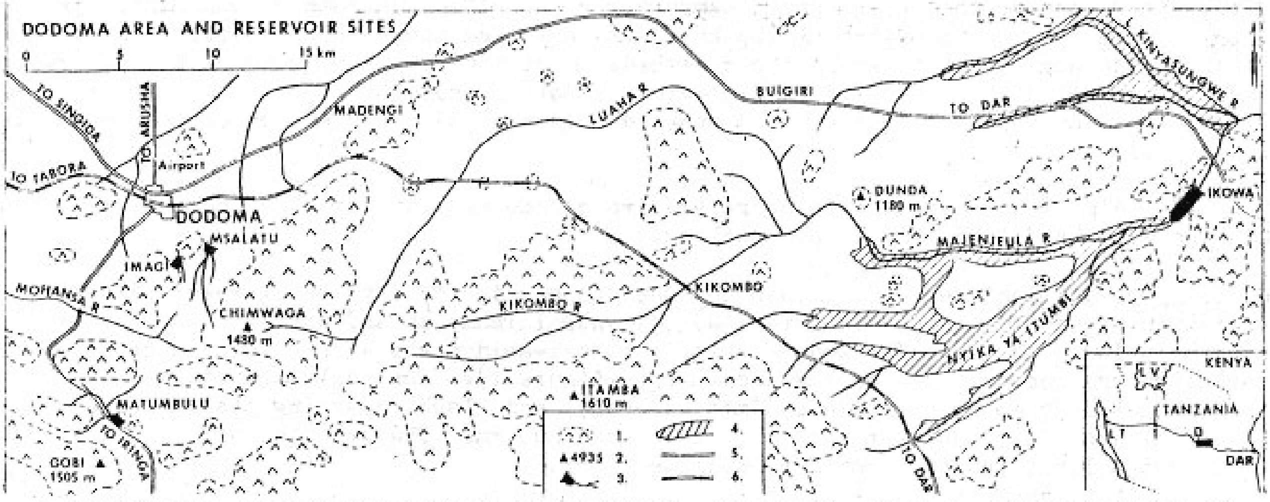
Kisongo catchment near Arusha is underlain by young volcanic rocks. The soils are dark, silty-sandy and derived from weathered volcanic lavas or ashes. The annual rainfall is about 800 mm and the dry season normally lasts 5-6 months. Some data on the five reservoirs and catchments are given in Table 1. All catchments are under intense land use and are much overgrazed by cattle. Cultivation and collecting of firewood also contribute to erosion.

The sedimentation rate in each of the reservoirs was determined by repeated surveying of cross-profiles. Inventories of the erosion features in the catchments were made by means of air photo interpretation and field checking (Figure 2).

Rainsplash and sheet wash are probably the most important types of erosion in the area that was studied. Gullies appear in distinct zones on the upper pediment slopes near the foot of the inselbergs in the Dodoma catchments. In the Kisongo area the gullies are cut along cattle tracks near the main drainage lines of the catchment. No new areas of gullying could be traced by comparison with old air photographs in the Dodoma catchments but extension of some single gullies had occurred since the early 1950s.

The reservoirs have very high rates of sedimentation. Three of them, Ikowa, Matumbulu and Kisongo, have very short expected total lives of 25-30 years and still shorther economic lives. The expected total life of a reservoir is the period from the construction of the dam to the time when the whole storage volume is filled with sediment. The economic life of a reservoir is the period during which the economic advantages of using the reservoir outweigh the investment costs; the reservoir's economic life usually ends when sediment fills 50-75 percent of the total storage volume. The annual sediment yields corresponding to the sedimentation in the surveyed reservoirs vary from 200 to 730 m^3/km^2 per year (mean values for longest period of available data). In addition, large volumes of sediment have been deposited upstream of the reservoirs as thin, sandy sheets on lower pediments, as sand fans along stream channels and as silty-clayey layers on mbuga floodplains, the latter occurring particularly in the Ikowa catchment (Figure 1).

Fig. 1



Location map of reservoir sites, Dodoma area, Tanzania. Key: 1. Bedrock hills of granite or mignatic granite. 2. Summit with altitude in meters. 3. Reservoir investigated in the Duser project. 4. Floodplain of "mbuga" type. 5. Road. 6. Railway. On insert map: L V = Lake Victoria, L T = Lake Tanganyika, D = Dodoma, Dar = Dar es Salaam, black rectangle marks area covered by main map

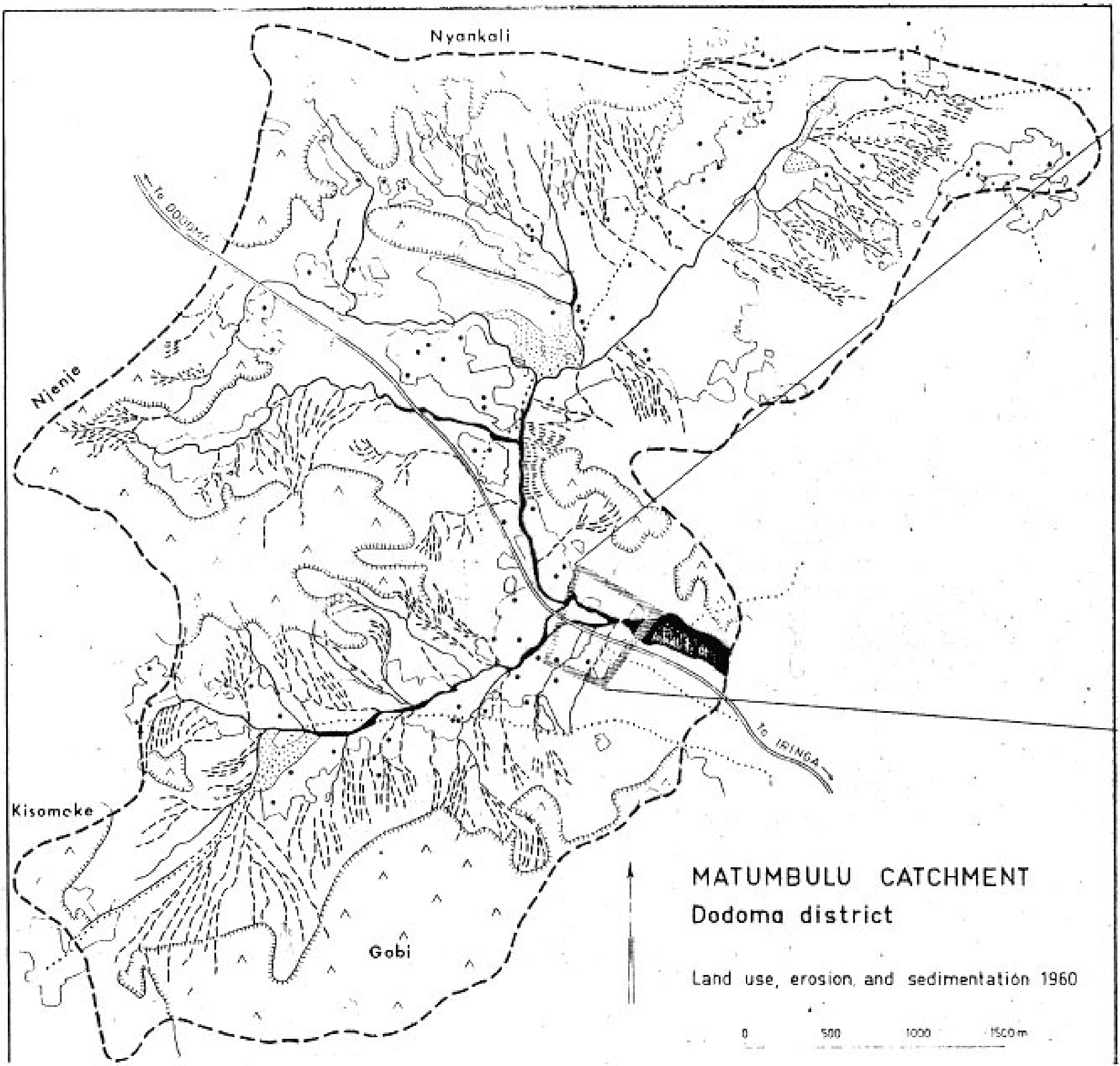
Table 1

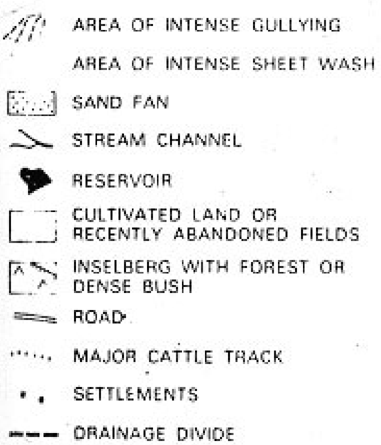
Place	Catchment area km^2	Relief ratio m/km	Annual sediment yield m^3/km^2	Soil denudation rate* mm/year	Period	Expected total life of reservoir
1. Ikowa	640	730/50	195	0.20	1957—69	30 years
2. Matumbulu	18.1	257/4.4	729	0.73	1962—71	30 years
3. Msalatu	8.7	183/4.1	406	0.41	1944—71	110 years
4. Imagi	1.5	122/1.6	601	0.60	1930—71	190 years
5. Kisongo	9.3	225/5.7	481	0.48	1960—71	25 years
6. Morogoro	19	1598/6.8	280	0.28	1966—70	no reservoir
7. Mgeta-Mzinga	20	1325/6.2	13 500	14	1970-02-23	no reservoi

* Data on denudation rates are based on reservoir sediment surveys [Nos 1—5], sampling of suspended load in streams [No. 6] and total volume of landslide scars resulting from one rainstorm of two hours duration [No. 7]. No. 7 is the only case based on volumes of erosion scars. Hence it is not directly comparable to the other cases which are based on sediment deposits or sediment load in streams. Relief ratio is maximum relief of catchment in meters, divided by length of catchment in kilometers. Economic life of silting reservoirs is shorter than expected total life until 100 percent filling

Soil denudation rates in seven catchment basins in Tanzania. Nos. 1–5 are catchments with reservoirs in semi-arid areas. Nos. 6–7 are catchments in the Uluguru mountains with high precipitation and no reservoirs

Fig. 2





Map of land use, erosion and sedimentation, Matumbulu catchment, Tanzania. Based on air photographs from 1960 and field checking during 1969–71. Note the zones of erosion and deposition: gullied upper pediments with intense sheet wash, cultivated lower pediments, stream channels with three sand fans and reservoir with heavy sedimentation. Map by C. Christiansson. Area of Figure 3 indicated by frame.

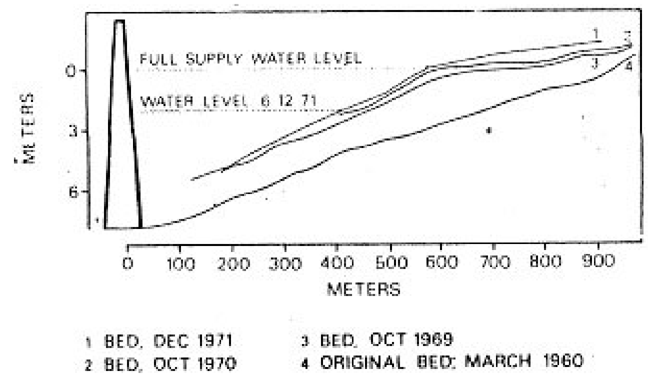


Fig. 3 Long profiles of Malumbulu reservoir, 1960–71. A sandy delta is rapidly filling the reservoir. The gradient of the accumulation is slightly less than the original stream channel above full supply level, slightly more below that level. Prediction of 100% filling by 30 years after construction. Potential use of filled reservoir as groundwater storage should be investigated.

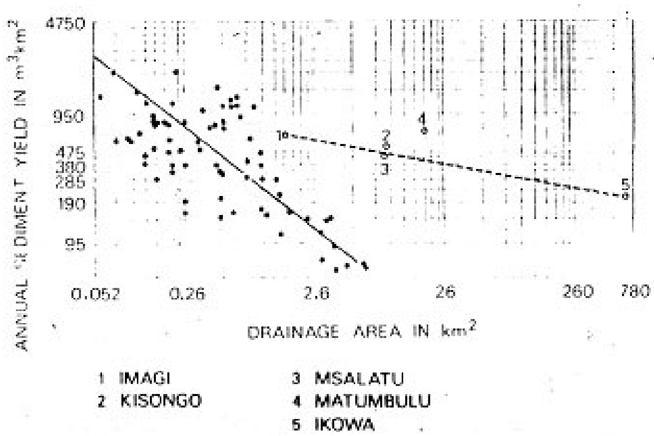


Fig. 4 Relation of mean annual sediment yield to drainage area for five catchment basins in Tanzania (open circles) and 73 catchments in eastern Wyoming (closed circles); the latter after Schumm and Hadley (11). Decrease of specific sediment yield with increasing catchment area is evident in both groups but is less marked in Tanzanian cases.

The reservoir sedimentation corresponds to a soil denudation rate of 0.2-0.73mm per year. Sediment yield in m^3/km^2 has been transformed into values of soil denudati rate under the assumption that the dry bulk density of sediments as well as soils is 1.5 g/cm^3. A bulk density close to 1.0 is characteristic for topsoils of the area, so the topsoil denudation figures may be more relevant if 50 percent is added to the values given in Table 1. Most of the reservoir floors have been surveyed when they have been dry, with compacted but cracked clayey sediment (4).

Table 1 and Figure 4 summarize data from the five catchments at Dodoma and Kisongo.

The figures for specific sediment yields decrease with increasing drainage area, due to sedimentation in the catchment (Figure 4). Therefore, sediment yields from small catchment basins (a few km^2 in area) reflect most closely the erosion in the catchment.

5. WATERSHED MANAGEMENT TO COMBAT RESERVOIR SEDIMENTATION

Controlling erosion and increasing the life of the reservoirs are mainly questions of better management of grass and other vegetation in the catchments and protections of harvested fields against splash and sheet erosion. Deduction of stock numbers, of overgrazing and of excessive burning of grass and mulch is necessary in order to combat erosion and lengthen the useful life of the reservoirs. The type of sediment which fills a reservoir is of great importance for its continued use after is has silted up. A reservoir which is filled with sandy or coarser sediments can used for groundwater in the future. The potential should be further investigated.

Reservoir surveys to document the rate and type of sedimentation and to establish the remaining life of reservoirs should be undertaken as standard practice for all existing and planned reservoirs in semi-arid areas. Reservoir maps and profiles should be made and sedimentation pegs established to make later comparisons possible.

In addition to the reservoir surveys, mapping and monitoring of erosion in the catchment should be performed to define areas and rates of sediment production.

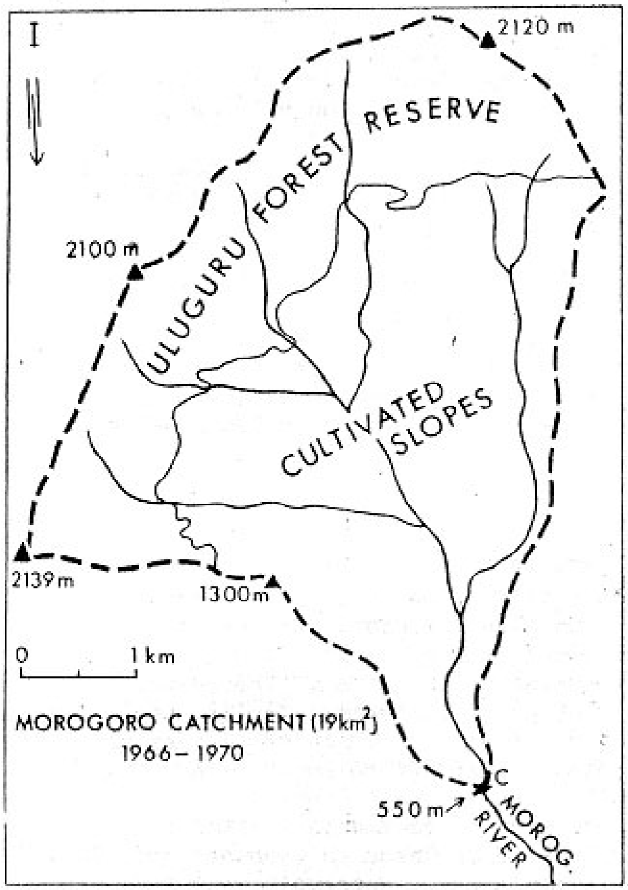
6. DEFORESTED MOUNTAIN SLOPES

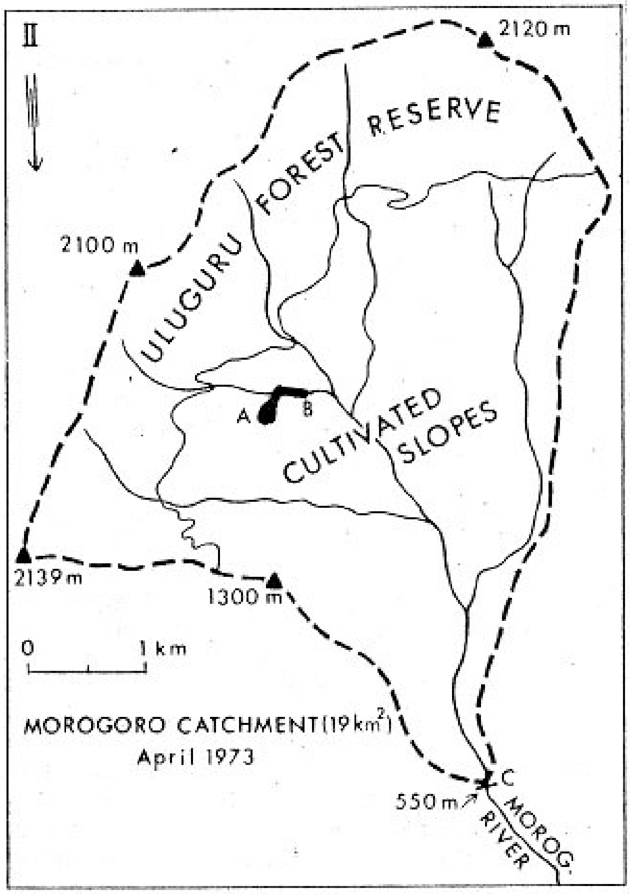
The Uluguru Mountains in Tanzania were selected for the study of an area representing deforested mountain slopes with intensive cultivation. In one of the study catchments, a three-year sampling and analysis of suspended sediment load in the Morogoro River was carried out (3). The catchment area is 19.1 km^2. The elevation ranges from 550 m at the stream gauge, to 1450 m at the rainfall recorder, where a montane rainforest reserve begins, to 2100 m altitude on narrow mountain ridges in a rainforest zone (Figure 5). The annual precipitation is about 900 mm at 530 m altitude and 2 400 mm at 1450m altitude. The soils are sandy loams, weathered from the local basement bedrock of gneisses and granulites.

Another study catchment in the Uluguru is the Mgeta Valley, which is similar to the Morogoro catchment in geology, landforms, climate, vegetation, soils, population density and land use in general. On 23 February 1970, this valley was hit by an intense rainstorm during which 100 mm of rain fell in two hours. It triggered more than 1000 landslides and mudflows and caused serious damage to human life and property, including crops and land (9).

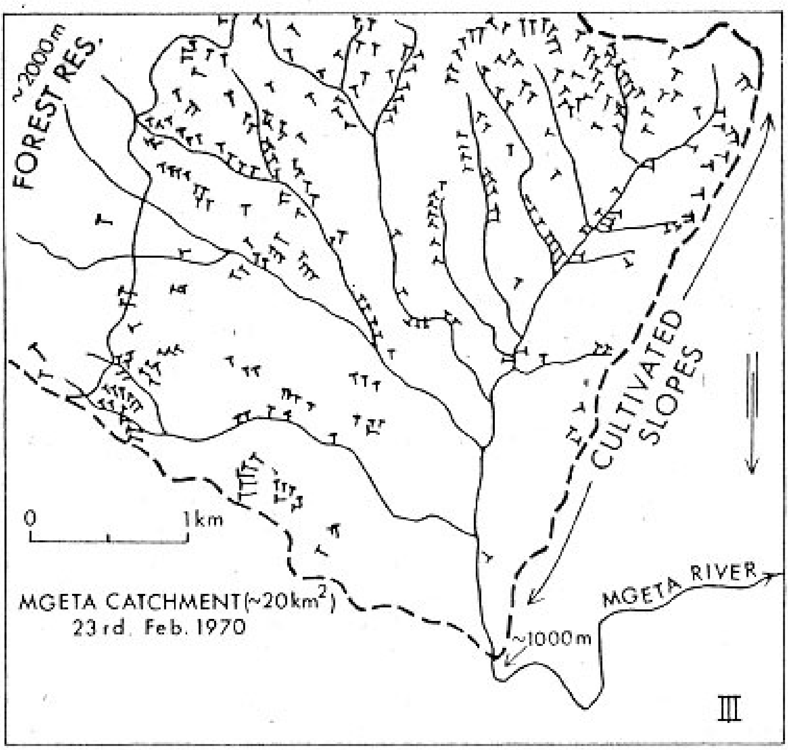
These and other catchment studies in the Uluguru Mountains showed the importance of three kinds of erosion hazard (Figure 5).

Fig. 5





Three maps showing three major types of erosion on deforested and cultivated slopes in tropical mountains, as represented by the Uluguru Mountains in Tanzania.



Map I. Annual "average" slopewash 1966—1970 from cultivated slopes caused a soil loss of 7500 tons/year, measured as suspended load in the Morogoro River (3).

Map II. In April 1973, a large landslide within same watershed area as shown on Map I, started at A, left 26 000 tons mudflow at B, plus unknown sediment load beyond C. It blocked the water intake of the town of Morogoro, silted up the water pipes and damaged the water supply for weeks (9).

Map III. A large number of small landslides triggered by a heavy rainstorm of 100 mm on February 23, 1970. Slides indicated by T-symbols. A few landslides that occurred in the forest reserve, and the more than 800 that occurred on deforested slopes below the forest reserve boundary (8), moved 400 000 tons of soil and regolith into streams.

Annual soil losses by slope wash from cultivated slopes are high. Protection measures: grass barriers, terracing, cover crops, mulching (Map I).

At intervals of one or a few decades, maximum losses are caused by extreme rainstorms and numerous small landslides. Protection measures: planting of forest belts in critical zones (below ridge crests, above roads, near stream sides) (Map III).

At intervals of several decades, single, large landslides of 100 000 tons occur. Protection mainly by awareness of landslide danger in watershed.

1. Sheet and rill erosion occurring every year on cultivated slopes, although highly variable in severity, depending on the intensity of the individual rainstorms.

Terracing, grass barriers, cover crops, mulch cover on bare soil and reduced burning of vegetation are simple but effective methods of protecting against these kinds of erosion.

2. Numerous small debris slides and mudflows triggered by extremely intensive rainstorms with a periodicity of several years or decades (9).

Planting of shelter belts of forest in critical zones, to stabilize the soil and regolith with tree roots, is recommended for protection against this kind of hazard.

3. Single, large landslides, many meters deep. These are rare in time and space as compared to category 2, but can have far-reaching destructive effects through stream sedimentation (The Palu example) (10).

As such deep landslides can probably not be avoided, even by tree planting, there must be an awareness of the potential destructive force of large landslides, and this must be taken into account in water supply management.

7. CONCLUSIONS

Soil erosion by running water is a growing problem in many countries in Africa, due to increasing pressure on marginal lands for grazing, cropping or wood collection. Erosion has very marked effects on the flow of water and sediment in streams. Thus erosion/sedimentation systems have to be studied together in natural catchment basins, under different environmental conditions and different types of land use, to clarify the mechanisms and rates of active processes. Such studies or "catchment diagnoses" provide a sound basis for reclamation plans, as these have to be adapted to the local ecological and social conditions to be successful.

Every land and water development scheme should be combined with critical evaluation of its impact on the environment and on man. It is necessary to observe critically the reactions of the environment to exploitation, and to draw conclusions for better land use from these observations. Reliable reference data maps, photographs, descriptions must be obtained for land and water development projects, so that it is possible to compare the situation before, during and after implementation of a plan. By means of repeated comparisons or monitoring, initial mistakes can be recognized and corrected.

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B. Forestry: Watershed Management and Soil Conservation

Paper No. 9

CONSERVATION OF UPLAND WILDLANDS, FOR DOWNSTREAM AGRICULTURE

by

S.H. Kunkle and D.A. Harcharik 1/

ABSTRACT

This paper describes in broad terms the objectives of natural resource conservation and restoration for non-agricultural uplands, particularly from the viewpoint of protecting downstream interests. The function of forests in moderating runoff is discussed. A number of common conservation measures are briefly described, including measures for forest roads and for logging, the concept of restoration through afforestation, the use of buffer strips along streams, techniques of vegetation modification and combined mechanical/biological methods for the restoration of eroded slopes. The role of the vegetative cover in the water balance is illustrated by examples.

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1. INTRODUCTION

The upper parts of many river basins consist of forests, grazing areas, brushy zones and other non-cultivated lands, often in steep terrain, which we refer to collectively as "wildlands". These upper catchments are not only the areas where rivers find their origin but also typically the zones where the most precipitation falls. Thus, upstream wildlands are the source of the bulk of available water in many drainage basins. For this reason, it is logical that agricultural development efforts, such as irrigation schemes, should concern themselves with upstream conservation, including the wildlands.

This paper describes natural resources conservation and restoration in non-agricultural uplands, particularly from the viewpoint of protecting downstream interests. An attempt is made to describe some of the main physical and biological processes which are involved, for example, the function of forests in moderating surface runoff. Secondly, the paper summarizes the procedures practised by foresters and other wildland managers. It is recognized that if lands are properly classified as to their most suitable use, most steep areas will be best used as forest land, whereas many of the more fertile, flatter areas would be put to agricultural use. In this paper, we concentrate on the steeper slopes.

2. LAND USE UPSTREAM - IMPACTS DOWNSTREAM

2.1 Evidence of Land Use Effects on Streams

There are ample field examples which illustrate how land use practices in wildland catchments affect land development downstream, both positively and negatively. To take one case, an irrigation project which recently constructed concrete canals in a Caribbean country was inundated with nearly a metre of sediment only a year after the construction. The sediment was deposited by torrential flows from watersheds upstream, where shifting cultivation and the farming of steep hillsides are causing severe erosion.1/ In a similar example in central Africa, a concrete reservoir was constructed to serve as water supply for a town of about 5 000. Four years after construction, the reservoir was already half filled with sediment and losing its usefulness. In this case, heavy grazing above the reservoir caused most of the erosion.1/

The importance of upstream areas is likewise underscored by sediment problems in rivers. In the estuary of the River Plate at Buenos Aires, silt dredging for shipping costs about $10 000 000 per year. Mineralogical studies by the Authority for Water and Power show that some 80 percent of this 100 000 000 tons a year of sediment comes from one heavily grazed sub-basin, the Bermejo River. This small mountain region is only a very minor area of the whole drainage basin (4 percent) but contributes 80 percent of the sediment problem. A government commission has been set up to tackle this problem of land use (Pereira, 1973).

One may find similar types of land use problems on a much larger scale in Asia. Sterling (1976) gives a description of floods in the Himalaya region, summarizing the impressions shared by many natural resource specialists that downstream flooding is highly related to upstream land use impacts, such as deforestation. Regarding the cost of floods to the region, Sterling writes, "until 1970, the average cost (speaking of floods in India) was roughly $120 million a year. From then through 1973 the average leaped, with a record of $750 million in 1974".

Such field examples are common, although not well documented, but these scattered references give an indication of the importance of upstream conservation for the protection of downstream developments, especially reservoirs. In all cases, upstream actions -

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1/ The two examples cited are based on personal observations in the field by S.H. Kunkle.

shifting cultivation, over-grazing, de-forestation, uncontrolled road building, wildfires, etc. - were the main cause of downstream river problems.

2.2 Summary of the Main Downstream Effects of Land Use

The hydrological response or streamflow of a basin is the most obvious index of the adverse effects of land use. The streamflow likewise will reflect good land management practices upstream, including protection or restoration measures.

The adverse effects of upland erosion may be summarized under four principal categories of problems (as seen from "downstream").

a. siltation (main problems: reservoir silting; degradation of water quality);

b. torrential conditions (main problems: farm field losses along streams; village destruction; bedload impacts; river channel cutting);

c. higher peak streamflows (problems: flooding; greater tractive forces, meaning more bedload transport);

d. less infiltration, hence less baseflow (problem: tendency for streams to dry up earlier or be lower during the dry season).

These four categories of problems are summarized in the schematic graph of Figure 1. An individual basin will not necessarily demonstrate all four types of problems, although often they occur together.

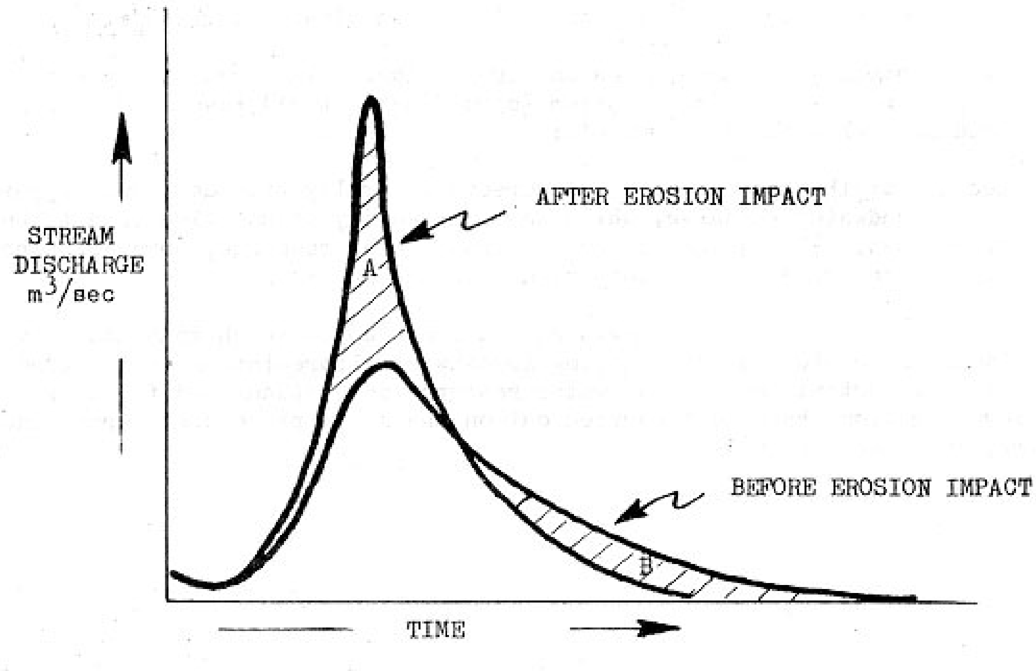

Fig. 1 Schematic illustration of the principal effects of erosion of an upstream catchment on the hydrological regime, taking a hypothetical hydrograph of storm runoff from a basin "before" and "after" severe erosion.

Monetary values can be attached to the two hatched areas "A" and "B" of Figure 1 for cost/benefit comparison, for example: benefits of the land - exploitation (value of the timber harvested) vs total costs of the downstream floods. From a restoration viewpoint, the approach would be: benefits of halting siltation or other damages (e.g. saving the cost of river dredging) vs costs of alleviating the problem through afforestation or other restoration work. To take a current example, a 20-year programme of upstream watershed protection and management on the Loukkos Watershed, Morocco, is aimed at reducing land degradation by 10 percent every 5 years. It is calculated that, in terms of the dam under construction, this would extend the dam's sediment storage capacity from 37 to 65 years (Comité National Marocain, MAB, 1976). The monetary benefit of an extra 28 years of reservoir use would be the amount which one could justify spending for conservation. Profits resulting from the conservation (e.g. wood production) also could be included as "secondary benefits".

3. ROLE OF FORESTS IN REDUCING FLOODS AND SEDIMENT

For steep topography, a forest cover is often an excellent protection for streamflow, because of the following reasons:

i. infiltration and percolation are typically much higher under a forest cover than if the same catchment is used for agricultural crops (see Table 1); therefore, more water enters into the ground, and less flows overland;

ii. forest soils typically develop a higher detention storage capacity than do soils of farmed fields, largely due to root development; this provides extra storage for flood water protection;

iii. in general, trees tap and transpire water from deeper in the soil, which also provides storage space for protection against floods;

iv. during storms forest canopies and their floor litter can trap up to 20 mm of precipitation by interception (according to field research), again holding back some of the runoff;

v. because of the above processes, forests generally provide a good opportunity for groundwater recharge, which may improve dry season flow conditions downstream. (The actual amount of groundwater recharge, however, also depends on transpiration losses, as discussed later.)

In other words, a forest cover maintains storage space which moderates the runoff pattern. This is why protection of existing forests or afforestation of degraded upper catchments can be important in terms of water resource development and flood protection. Many field investigations have been carried out on the above processes (Sopper and Lull, 1967; Pereira, 1973 and others).

Table 1 INFILTRATION RATES FOR FOREST AND AGRICULTURAL LAND (after Molchanov, 1963)

Soil porosities are similar, varying from 48 to 59 percent

Land use	Age	Infiltration rate mm/min
Oak forest	26	11.4
	60	12.5
	180	7.0
Ash forest	18	20.7
	36	22.9
	65	16.8
Meadow		6.0
Plough Land		1.2
Pasture		0.3
Forest felling area		7.6

It must be remembered that the above listed hydrological benefits are greatest for a natural mature forest. When a forest plantation is first established, it resembles an agricultural field in terms of its hydrological response, especially if soils have been ploughed or disturbed when removing a previous stand of mature trees. As the forest plantation develops, the benefits which it provides vis-à-vis hydrology will come closer to resembling that of the natural forest.

To cite an example of the mainly beneficial effects of afforestation, planting 100 000 trees (mainly pines) on severely eroded sites in a TVA[1/] area reduced the peak rates of streamflow (m^3/sec) from the catchments by an impressive 90 percent, with the sediment reduced by 96 percent. However, the total volume of runoff (i.e. m^3) was reduced by about one-half; therefore, the flood and sediment protection benefits were not without a trade-off in terms of the total water yield. In this case, the reduction of peak flows and sediment were more important than the loss in water volume, since the "loss" came largely from the high flood peaks.

Another example of afforestation effects is shown in Table 2, where the runoff and sedimentation from abandoned farm fields and poor deciduous forests are compared to those from areas afforested with pines.

1/ Tennessee Valley Authority, southeastern U.S.A.

Table 2 AVERAGE ANNUAL RUNOFF AND SEDIMENT FROM THREE VEGETATIVE COVER TYPES IN NORTHERN MISSISSIPPI

(1958-60 studies by Ursic, 1963)

Vegetative Cover Type	Runoff		Soil loss (kg, ovendry, per hectare)
	Loess soils	Loess and coastal plain soils 1/	
	.... cm	....	
Abandoned fields	28	8	398
Depleted hardwoods	13	7	280
Pine plantations (Pinus taeda L.)	5	0.5	39

1/ average of 2 catchments.

4. WILDLAND CONSERVATION AND MANAGEMENT

Considering the beneficial role of upland vegetation, especially forests, for regulating streamflow, it would be easy to conclude that one of the primary causes of downstream problems is vegetation destruction upstream and that therefore we need only to leave upper catchments as protection forests. In many cases this is precisely the answer, but in most countries the need for timber resources and the pressures for land use in general are much too great to allow large zones of upstream land to go un-used. We therefore need practical management guidelines for making proper use of wildland watersheds while at the same time protecting downstream interests. It is not an easy task. Wildlands are often steep, marginally productive and - as opposed to good agricultural fields - can attract only modest investments. Therefore, many of the well-known options available to agronomists, such as bench terraces, are generally not relevant. The fact that very large areas usually are involved also spreads the efforts thin.

We shall review some conservation measures and guidelines which are useful for managing or restoring degraded wildlands. Development of sound guidelines demands an understanding of certain hydrological or biological functions or processes. The runoff process is particularly important, since conservation in wildlands is largely aimed at controlling overland flow.

4.1 Planning Road Construction

One of the initial problems which plagues many wildlands is the opening of the area to ready access through road construction. The risk of erosion is high when new roads are constructed in wildland areas. These access routes can easily be the main erosion source, especially if ill-designed or "no design" roads are bull-dozed into hillsides, as is often done by poorly supervised logging operations. This brief section only highlights a few of the more important questions regarding road construction; for further details on the subject an FAO paper by Megahan (1976) is in preparation.

Planning is the most essential point. Roads should be well-planned beforehand so that a minimum area of the watershed is disturbed. There are also several specific rules of thumb for avoiding erosion which are based on natural terrain features, geological factors and the engineering methods - all which need to be taken into account in the construction. The essential objectives of proper road construction, in brief, are to avoid concentrating surface runoff and to by-pass risky sites (e.g. slide prone areas) when selecting the road placement.

Drainage is another major point. If roads are not drained, they concentrate runoff and can become "instant gullies". The simple drainage devices shown in Figure 2 can prevent this problem by spreading overland flow out rather than letting it concentrate.

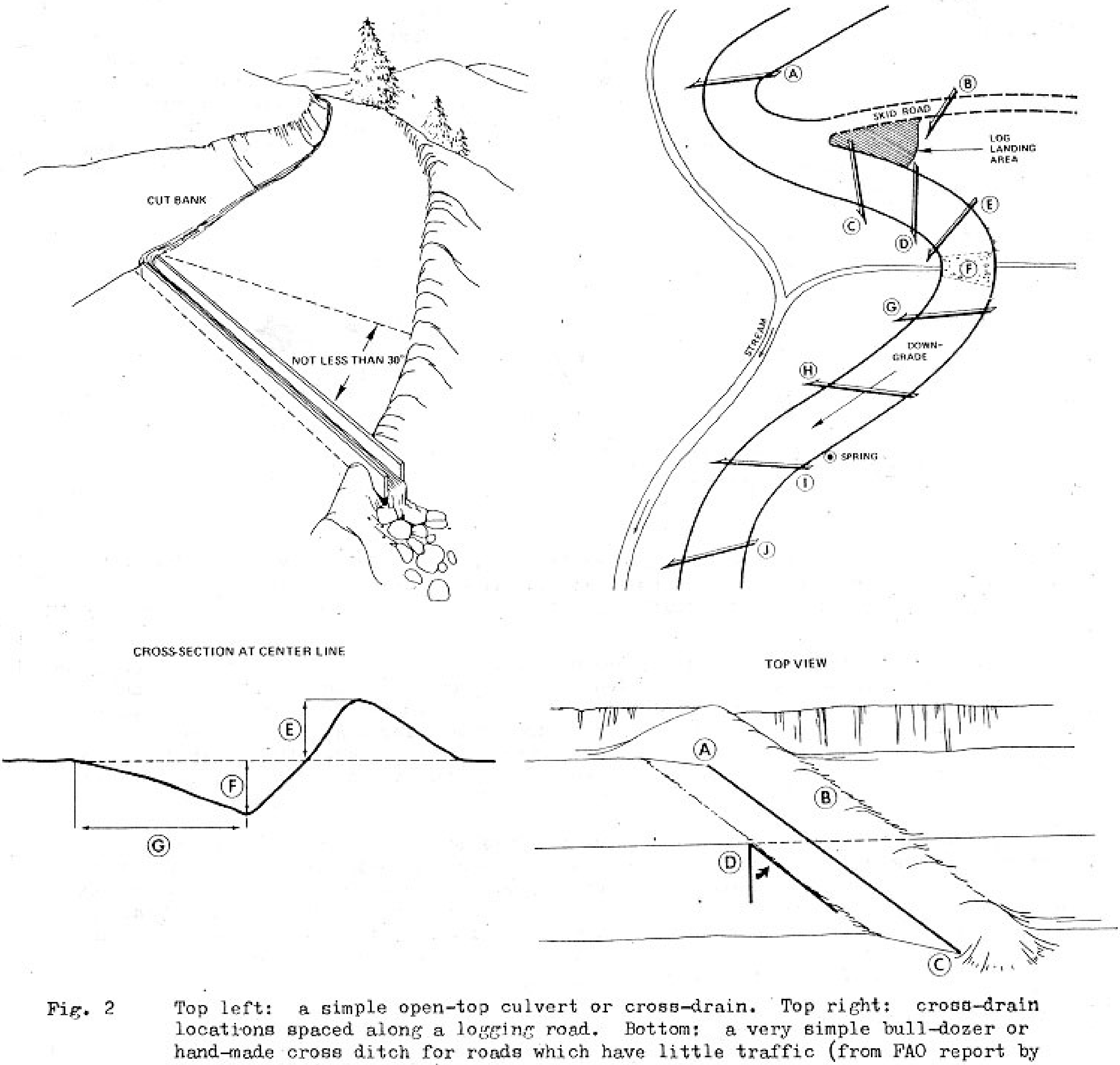

Fig. 2 Top left: a simple open-top culvert or cross-drain. Top right: cross-drain locations spaced along a logging road. Bottom: a very simple bull-dozer or hand-made cross ditch for roads which have little traffic (from FAO report by Megahan, 1976, in press).

4.2 Timber Harvesting

Careless timber harvesting practices can lead to severe sediment problems. For example, in one logging study, turbidity in the stream below a clear-cut area reached 56 000 parts per million, compared to only 5 ppm in adjacent unlogged streams (Hornbeck, 1968). Turbidity is an optical index of suspended sediment. However, if logging is done in conjunction with suitable conservation measures, the sediment yields will not be appreciably higher from logged catchments than from undisturbed areas.

The engineering method for logging in particular is important, and the hydrological principles involved are not unrelated to those for road construction - i.e. mainly to avoid risky sites and the concentration of runoff and to minimize soil disturbance. For example, as sketched in Figure 3, uphill logging by cables avoids concentrating runoff. The skid trails of downhill tractor logging on steep terrain, on the other hand, concentrates runoff, resulting in a much higher erosion risk. It is critical that any temporary tractor trails be immediately broken up by cross-drains after use, to divert runoff (as in bottom, Figure 2). If downhill tractor logging is used, there are devices which lift the logs to reduce the ploughing effect of log skidding.

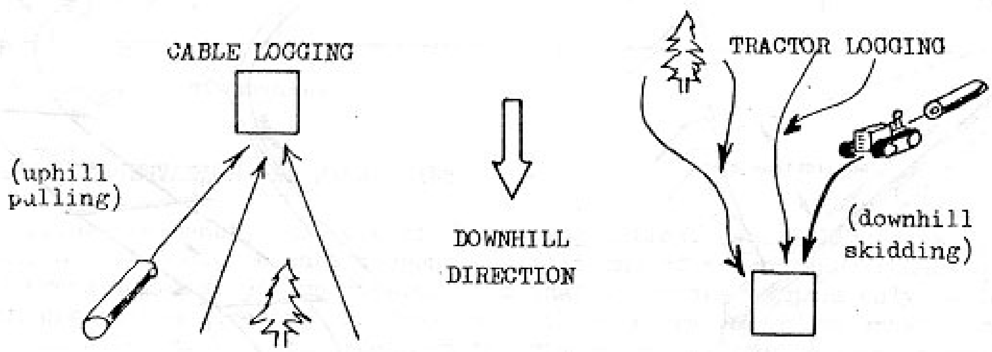

Fig. 3 Simple sketch of uphill cable logging and downhill tractor logging on steep lands, illustrating how tractor skidding makes trails to concentrate the surface runoff.

Even with cable logging there are major differences in erosion impacts, depending on the method used. In one example, a small-size, truck-mounted cable skidder (60 m cable) disturbed 25-30 percent of a catchment with the temporary roads it needed, whereas larger cable systems which could reach out several hundred metres for logs disturbed only about 5 percent of their catchments with road construction (Megahan, FAO, 1976). Experiments with helicopter and balloon logging are interesting from a conservation viewpoint, but it seems unlikely that these methods will become common.

Another important consideration which deserves mention in connection with timber harvesting is the choice of silvicultural system. Where one objective is to keep erosion at a minimum, clearcutting is the least desirable silvicultural system because it removes most of the protective tree cover and results in the heaviest soil disturbance. Other silvicultural systems which harvest fewer trees over a period of years create less of an erosion hazard. Early and abundant natural regeneration is also desirable because it reduces the period of high erosion risk.

4.3 "Buffer Strips" and Protection Zones

"Buffer strips" or "filter strips" are ribbons of trees or other vegetation which are left undisturbed along stream channels (or lakes) as a protection against erosion and sedimentation during logging.

A review of the phenomenon of surface runoff helps to explain the value of buffer strips. In many forest lands - as opposed to open fields - surface runoff is rather rare, at least on upper slopes. During a storm only a small part of a catchment, basically along the channels, yields surface runoff, while on upper slopes high infiltration occurs. For this reason, the areas most sensitive to erosion in forested lands are likely to be the streambank zones, while the upper slopes are more stable. Some landslides along streams occur, however, even in virgin forests.

If we clear the forest, there is very likely to be a sharp increase in surface runoff, which can lead to erosion and sediment movement. The implications for leaving uncut buffer strips are obvious. First, they protect the sensitive stream channel environs and, secondly, they act as a filter for any sediment coming from upslope. The steeper the slopes adjacent to the channels, the wider the buffer strips must be. The field guidelines of Table 3 give an indication of the size of buffer strips needed.

Table 3 RECOMMENDED HORIZONTAL WIDTH IN METRES OF BUFFER STRIPS ALONG STREAMS (from Balmer et al, 1976), showing distance on each stream side, between the channel and the upper edge of the buffer strip

	Percent Slope						
Erosion hazard of the strip's soil	0	10	20	30	40	50	60
Slight	9	17	24	32	39	47	54
Moderate	12	23	30	42	51	61	71
Severe	15	27	39	51	63	75	87

It is apparent from the above discussion of runoff that large size clear-cuts are more disturbing than smaller openings. We also know from erosion prediction equations, that the longer the slope along which runoff flows, the greater the erosion potential. It is preferable, therefore, to clear-cut in small blocks, in alternate years.

It should be noted, however, that in certain downstream catchments, especially in arid regions, strips of trees along streams may be undesirable because of their high water consumption. But typically in upper, forested catchments the erosion protection value of the buffer strips far outweighs any water loss disadvantages.

4.4 Fire Control and Fire as a Tool

Fires, usually uncontrolled, are a familiar occurrence in wildlands and a major cause of erosion and sediment. The influence of fires on streamflow is well known. Flood peaks may be several hundred times higher after wildfires sweep through a basin (according to research by Krammes and Rice, 1963, and others). After fires, movement of sediment and debris is greatly increased. Wildfire prevention and control therefore is an important part of conservation.

One possible management tool for some vegetation types is "controlled" or "prescribed" burning, which consists of deliberately and periodically burning vegetation at a desired time, in part to avoid the build-up of fuels which can lead to much more damaging wildfires. Burning the understory of most pine forests, for example, will reduce fire hazard.

Controlled burning at relatively low intensities is used for other managerial benefits as well. In pine forests it reduces the invasion of undesirable, shade-tolerant tree species.

It also appeals to land managers attempting to favour one type of vegetative cover over another, for example, grass instead of brush.

Caution must be exercised, however, as not all vegetation types lend themselves to this technique. Also if poorly timed and irrationally applied, especially to steep slopes, controlled burning may increase, instead of decrease, erosion.

5. RESTORATION OF STEEP ERODED UPLANDS THROUGH AFFORESTATION

5.1 The Effectiveness of Afforestation

On uplands already denuded by wildfires, shifting cultivation, poor logging practices or heavy grazing, restoration is a conservation priority. Mechanical structures, such as check dams and small terraces, are useful but are normally only temporary control measures to aid in revegetating eroded wildlands. The best overall means of providing permanent erosion control on wildlands is by establishing and maintaining a dense vegetation cover over the entire catchment. Long-term conservation work, therefore, usually involves biological measures, such as afforestation or range improvement - which may be done complementary to mechanical measures.

Vegetation on wildlands, whether trees, grass or various dense brush, is effective for erosion control largely because it:

i. provides a protective canopy as well as a mat of litter for protection against "splash" erosion by rain (especially critical in intense tropical rainfalls);

ii. physically binds the soil with roots; in some cases the roots may anchor the soil mass to the parent material, which may reduce creep or land slides (important in steeper zones of wildlands);

iii. provides galleries of decayed roots in the soil, to facilitate rapid infiltration (important for flood control, but also to reduce surface runoff);

iv. increases the water absorbing capacity of the soil, by adding organic matter.

Some plants are much more effective than others for erosion control work. In this section, we shall mainly review the objectives and procedures of afforestation, while recognizing that it is but one of several possible erosion control measures. It should be underscored that afforestation is not a panacea for erosion problems on degraded lands. When the time required to establish a vegetative cover is an important consideration, herbaceous plants, such as grasses, grains and clovers, are preferred because they provide a quick cover and have the added advantages of being relatively cheap and easy to establish. Even aerial sowing is possible. Also, severely degraded, barren "moonscapes", too poor for agriculture, may also be too poor to grow trees. In such cases, establishing grasses or simply letting native vegetation return naturally may make more sense than afforestation and, in fact, may be preferable from the viewpoint of immediate erosion control. Nonetheless, as a well-established tree cover affords the most effective overall protection and usually allows for eventual economic return through the production of wood products, afforestation should be considered as a possibility for many eroded areas, at least at a second stage.

5.2 Selecting Tree Species for the Job

The choice of one or more species of tree(s) for erosion control is based largely on the specific climatic and soil conditions of the planting site, using species and provenances which are most adaptable. Morphological traits are also important. For most tree species, especially those which are wide ranging, selection of the correct provenance is as important as selecting the species itself. For example, important differences in growth, adaptability and morphology have been proven for different provenances of Eucalyptus camaldulensis, Pinus caribaea, Pinus sylvestris, Pinus taeda and many other tree species.

The following factors should be sought in selecting a tree species for erosion control:

- good survival and fast growth on impoverished sites;
- ability to cast a large amount of litter and form a dense crown;
- ease of establishment and need for little maintenance;
- deep and widespreading root system.

In addition, provision of some degree of economic return is usually sought. In most cases, therefore, it is desirable to select forest trees with the best combined erosion control/wood production benefit. Usually a compromise must be made in this request.

The final decision as to which species and provenance to use for wide-scale planting would ideally be made on the basis of results from comparative, replicated trials. Where such results are not generally available, interim decisions must be taken based on the limited information available. Where suitable local tree species occur, they are usually the safest choice, until trials prove otherwise. Certain tree species are of interest to the forester from a wood production viewpoint but are much less appealing in terms of conservation. For example, teak trees do little to retard surface runoff, according to some observers, because their flat leaf litter tends to "coat" the ground surface (personal communication, Wheeler, FAO, 1976). Pinus taeda, on the other hand, is known to be both a productive timber species in southeastern USA and highly effective in controlling erosion. Mixed plantations of two or more species may provide better erosion control, but they are usually less appealing to foresters from a wood production and management viewpoint than are monospecific stands.

5.3 Planting Approaches

In regions where rainfall is sufficiently abundant or well distributed to support at least a moderate ground cover, planting site preparation requires only a minimal effort sufficient to ensure that the introduced trees can grow without excessive competition from surrounding grass, weeds or other plants. But in cases where the natural vegetation is sparse or non-existent because of low rainfall, water and soil retaining structures may need to be constructed, to improve moisture conditions or to prevent surface flow from causing erosion. Mechanical measures which are commonly employed in combination with tree planting include terracing, various types of contour ditches or steps (also called gradoni or catastrips), tied-ridges, wicker work fences and a number of gully control methods.

There are two basic problems involving these mechanical measures in respect to afforestation: (i) the investment, e.g. for terracing, may be excessive in respect to the modest returns one can expect from wood production; and (ii) the probable lack of maintenance of structures in wildlands can destroy their effectiveness. Usually in wildlands mechanical measures are best concentrated on critical sites - along roads, on landslide areas, in major active gullies, etc.

Various disking, ploughing and other site preparation methods also have been used for afforestation work. Caution is required, however, since these techniques on steep slopes can lead to erosion. The protection guidelines used in reference to site preparation in the southeastern U.S.A. are shown in Table 4.

Table 4 MAXIMUM RECOMMENDED SOIL EXPOSURE DURING MECHANICAL SITE PREPARATION from U.S. Forest Service Timber Manual, Southeastern Region, 1973 as discussed in Balmer et al, 1976

Maximum Recommended Soil Exposure (%) During Mechanical Site Preparation		
Slope	Fragile Soils	Stable Soils
0	75	100
5	50	75
10	35	50
15	25	40
20	10	30
25	8	25
30	5	20
35		10
40		5

Though direct seeding is an important means of sowing grasses, it is generally not effective for establishing trees on eroded areas; seedling stock and cuttings are generally more successful. In mild climates, many tree species may be bare-root planted, but more often the harsh conditions of eroded sites require that tree seedlings should be raised in containers in the forest nursery.

The most important areas to vegetate for erosion control are those zones where surface runoff is more frequent, that is, near streams or temporary water-ways and on steep slopes. Planting spacings in such areas should be closer than on sites where runoff is less. The main objectives should be early tree crown closure and heavy litter build-up. The distance between trees can be adjusted to the degree of erosion, with spacings as close as 1 x 1 m and occasionally closer on the most critical areas, such as gully bottoms. Wider spacings of 2 x 2 m and more are used on less actively eroding areas.

Where little or no site preparation is required or where planting is not restricted by any set arrangement, such as terraces or contour ditches, the planter is free to select each planting spot. He should seek those especially fertile spots, for example:

- areas of topsoil or other loose material sloughed from the rims and banks of the gullies and
- deposits of soil or sediment behind clumps of vegetation or other natural barriers, or other sites favourable for the small trees.

Where top soil is completely lost, on very steep slopes or other areas where no natural sediment-collecting barriers can be found, small brush sediment catches or "dams" may be constructed to collect sediment and retain moisture for the trees. These brush catches are made from brush piled across the water course to a height of 30-40 cm. They are not, however, suitable on flats and slopes that have eroded uniformly down to parent rock material. Here it is advisable to fill planting holes with top soil if available nearby. Placing a layer of mulch around the seedling is desirable as it protects it against further erosion and helps to maintain a high soil moisture content.

6. VEGETATION CONVERSION AND WATER YIELDS

There are numerous possibilities to change or manage the type of vegetative cover on wildlands. These actions must be carried out with some caution from an erosion and flood control viewpoint. For example, in a study in California, steep catchments were converted from essentially small trees and brush cover to a cover of shallow-rooted grass and herbaceous vegetation (Murphy, 1976). Grazing was carefully controlled. The runoff was increased by an average of 50 percent because the high transpiration of the trees was stopped. (The tree roots reached to 20 metres). After removal of the trees, however, land-slides, soil creep and mudflow began to occur in one catchment and sedimentation increased from 400 (pre-treatment) to 4 000 tons per year (post treatment) ... 10 times! In brief, the example shows that advantages - in this case better grazing and continued streamflow - must be weighed against the disadvantages, namely an enormous increase in sediment and higher peak flows.

More drastic conversion, from dense forest to grass, can be even more hazardous. Increased erosion and landslides are often associated with such vegetation conversions, according to Rice (1976, in press).

Whether one tree species consumes more water than another is a question often raised. Wicht (1949) concluded from studies in southern Africa that plantations of exotic trees did not consume more water than indigenous species. Other studies, however, indicate differences. For example, Bailly *et al* (1974), working in a rainfall area of about 2 000 mm/year in Madagascar writes, "without a doubt an old *Eucalyptus* forest consumes 100-200 mm of water more per year than a natural, mature forest" (in the basins where his research was carried out). Likewise, 15 years of research in southeastern U.S.A. show about 20 percent streamflow reductions when hardwoods are converted to pine plantations (Ursic, 1974). It is important to note that these examples are in situations where precipitation is fairly abundant. One also must underline that results of such studies are still rare in the tropics and that the scattered results are not entirely consistent. There is still much to learn on this topic. A number of factors are involved, but many of the differences between species can be attributed to differences in rooting depth, total biomass production and efficiency of water use.

Within an area where forests are managed, there also are a number of silvicultural techniques to increase total water yields while protecting streams against sedimentation. For example, in the mountains of Colorado (U.S.A.), experiments were carried out with strip clearcuts with the intention of increasing water yield from the catchment. The cutting pattern consisted of alternate clear cut strips of different widths, 1, 2, 3 and 6 chains (one chain = about 20 m), running normal to the contours; 40 percent of the area was cleared in these strips. Results of after-cutting are shown in Table 5. The greatest increase in water yield (right hand column) was immediately after cutting (1956). As the trees grew back, the water yield gains began to decrease.

Table 5 RESULTS OF FOOL CREEK TREATMENT EXPERIMENT
(from section 2, Jeffrey, In Gray 1970)

Years	Predicted Yield 1/ (cm)	Actual Yield (cm)	Actual Yield Minus Predicted Yield (the "gain") (cm)
1956	29	40	11
1957	50	58	9
1958	29	34	5
1959	27	35	8
1960	28	38	10
1961	22	28	5
1962	44	49	5
1963	14	18	4

Data: Rocky Mountain Forest and Range Experiment Station, U.S. Forest Service.

1/ based on pre-treatment data for the basin; figures here converted from inches and rounded to closest centimetre.

7. TORRENT AND GULLY CONTROL

A torrent is a natural channel or waterway with:

i. a small catchment;

ii. a steep channel gradient;

iii. a high fluctuation of runoff, after storms or snowmelt; and

iv. a high bedload transport with sedimention (Hattinger, FAO, 1976).

Torrents are a well-known problem in the Alps and Japan and a familiar phenomenon in Asian and Latin American mountains. The main correction techniques are check dams and use of streambank protection measures. The check dams, built across streams in a stair-step series, serve to stabilize the channels and halt bed erosion by collecting debris in the dams, thereby reducing the stream gradient and tractive forces. Another important feature of the dams is their support of the toe of steep slopes, to help halt mass hill-slope movement downhill.

The most knowledge on torrent control has been developed largely in the Alps (for geological reasons, the particular problem is much less common in North America). Torrent control is most effective if accompanied by biological measures of erosion control and land use improvements in the basin above the structures. Once torrents begin, structure work will likely be essential. Torrent work, as normally carried out in the Alps, demands a proper engineering design and can be quite expensive. Nonetheless, FAO torrent control work in Nepal has made use of labour-intensive approaches, using rock on hand (personal communication, O. Tautscher, Nepal).

Similar to torrents is the much more frequently occurring problem of gullies. Heavy grazing can cause this problem. Often a combined biological/structural approach is used to control gullies.

The types of check dams include:

a. loose rock check dams;

b. wire-bound loose rock check dams;

c. single-fence check dams (a wire fence, across the gully, supports the rock from the downstream side);

d. gabion check dams (made of prefabricated wire cages, filled with rock); and

e. brush or log check dams.

These and other structures are described by Heede (1976) and by his chapter in the FAO publication "Conservation Guide" (1976). In many developing countries, types (a) and (b) or (e) will be of greatest interest in wildland areas, because of their simple requirements for materials. It is important that the check dams be designed to handle the peak flows - and to not be eroded. This design also involves proper spacing along the channel. Where rocks are not abundant, brush or log check dams may be used.

Where an effective vegetation cover will grow, gradients of gullies may be controlled by establishing plants, without mechanical structures, in cases after re-shaping. An ideal plant cover for a gully should be dense, low in height and have a dense and deep root system. Typically in steeper, wildland areas some combination of mechanical and vegetative treatment is required.

8. WIND EROSION CONTROL

Wind erosion is not necessarily an upstream problem although we might point briefly to two "services" in this subject where foresters are able to offer their agricultural colleagues assistance: (i) shelterbelt establishment and (ii) sand dune stabilization.

In several countries, especially U.S.S.R., U.S.A., Denmark and Israel, the experience with shelterbelts has been well quantified in terms of the benefits to field crops. The shelterbelts cut field evaporation and reduce wind damages. Unfortunately, we have rather limited experience with the use of shelterbelts in developing countries. Sand dune stabilization, on the other hand, is a rather well-known and effective art in North Africa and Iran, among other areas. The normal approach is to construct small checker-board palissades or "micro-windbreaks" of dry materials so that trees, shrubs or grasses can be planted. Some surprisingly good results have been achieved. Eucalyptus gomphocephala trees in Libya, for example, are now over 20 years old and have produced some specimens over 50 cm diameter (Forest Resources Division, 1974).

9. CONCLUSIONS

From the foregoing discussion it should be evident that a number of techniques are available to land managers when developing and restoring upland catchments. These techniques can be tailored to provide downstream benefits - particularly through the reduction of erosion effects and the regulation of streamflow. Nonetheless, there are a number of areas where we need more technical information. For example, what species of trees are best for erosion control, for shelterbelts and other conservation uses? Which species waste the least water? We have little information on these types of questions in most developing countries, but instead extrapolate techniques, not always with success.

But by and large, the problems today are less of a technical nature and more a matter of narrowness of approach on the part of land managers. Too often wildland management for a single objective or a "dominant use" has prevailed. Instead, conservation of upland areas should be planned as an integral and important part of the overall land use planning for an entire basin. A logical first step is to conduct a land suitability evaluation for a given basin which is geared to answer a number of major questions, for example: Which areas can safely be placed under permanent cultivation? Which areas are better classified as forest or grazing lands? Where are the degraded sites in need of restoration? Which are the most actively eroding sites requiring immediate and special protective measures?

It is not enough, however, to define the fields of play and then to pursue separate and unrelated policies. Agriculturists and land and water resource developers must more and more cast their eyes upward, while foresters will need to look far below, beyond the forests. Water resources development schemes, for example, should routinely include planning for upstream conservation. To build a dam with appropriate investment in upstream protection is good economics in the long run, yet far too often this aspect of water resources development has received inadequate attention. In this respect, we need better knowledge of the ways to quantify and demonstrate the economic benefit of conservation. As conservationists, we have so far failed to present our case in economically convincing terms.

Where upland forests exist, their management should be tied closely to the interests of downstream water users, fully recognizing that harvesting practices and other activities are reflected in downstream effects.

In summary, upstream conservation should be part of the overall plan for the water, agricultural and other developments within a river basin and its sub-catchments.

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Paper No. 10

EXAMPLES OF SOIL AND WATER CONSERVATION PRACTICES IN NORTH AFRICAN COUNTRIES ALGERIA, MOROCCO AND TUNISIA

by

B. Bensalem 1/

ABSTRACT

This paper describes the principal erosion problems in Algeria, Morocco and Tunisia and the approaches applied to their resolution as reviewed in case studies from these countries. The topics of discussion include: water erosion and the biological and mechanical measures to control it; the types of shelterbelts in use; the techniques for sand dune stabilization; the desertification hazard and potential measures for its control; and consideration of the integrated and basin-wide approaches in relation to a better management of natural resources.

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1. INTRODUCTION

Throughout history, erosion of soil from sloping land during periods of intense rainfall has been a problem of North African agriculture, and conservation measures have been known and practised for centuries. Erosion of soil by wind has also been, and still is, a problem in some parts of the region. Erosion by water has become much more severe, particularly since power equipment was introduced for farming and made it possible to bring large areas of hitherto uncultivated lands on hillsides into cultivation. In arid and semi-arid areas this is resulting in a considerable loss of lands and threatens whole areas with desertification. Many soil conservation projects have been launched and large sums of money have been invested to carry out conservation work. In this report, we shall consider some of the region's soil erosion problems and discuss the approaches applied to their resolution.

2. EROSION

Anyone who has ever been caught in a heavy rainstorm in North Africa has witnessed some of the frequent, spectacular disasters caused each year by water erosion. Highways and railroads are damaged; low lands are flooded; streams and wadis are filled with muddy water. Part of this water accumulates in reservoirs or is transported to lakes or the sea. Since most of the rainwater has not been percolated into storage during the rainy season but has runoff, an aridification process develops, even in the sub-humid areas.

During the dry period, one can witness the havoc caused by high speed winds. The most spectacular phenomena in the dry areas are the blowing sand dunes, which not only encroach onto productive land and rangelands, but also engulf irrigated oases and threaten villages and human habitations. The following is a brief review of the magnitude of wind and water erosion in North Africa and some of the techniques used to control it.

2.1 Water Erosion

Erosion by water is by far the most serious phenomenon in the three countries. This is a result of the easily erodible, sedimentary parent rock, the steep slopes, high rainfall intensities and the destruction of the vegetative cover. The most important aspect is that the proportion of land with steep slopes is the highest in the humid and sub-humid zones of the region, where rainfall is greater than 400 mm. The Rif region in Northern Morocco is a typical example: 50% of the land has slopes of more than 50%; soils are predominantly clayey and the annual rainfall is 900 mm. In Algeria, areas stretching from the Saharian Atlas mountains to the Mediterranean Sea invariably receive high intensities of rainfall several times per year, with a mean value of 47 mm per 24 hours, which is about one to two times the threshold value for erosion. In Tunisia, the areas most badly affected by water erosion are situated in the higher rainfall areas of the north where wheat, the main crop, is produced.

Inherent in these countries is a long history of land exploitation and a marked increase of human population, which together are the direct causes of much of the disappearance of the vegetative cover. In Tunisia, the degradation of the natural vegetation has proceeded at a higher rate than in Algeria and Morocco. In 60 years, the Tunisian forest has lost one-third of its surface, not to mention the degradation of the two-thirds that still exist. Today the forested area comprises only 3.2% of the total area of this country, while in Algeria and Morocco it is 8.4% and 11% respectively.

Awareness of the necessity for soil and water conservation was originally generated by the tremendous loss of agricultural areas and the rapid siltation of reservoirs. The reservoirs constitute the major source of water supply for domestic, industrial and agricultural uses.

There was a need to assess the erosion hazard, not only to better appraise its magnitude but to design appropriate conservation programmes. In Tunisia and Morocco this has led to intensive studies of the basic erosion process and erosion intensities on many watersheds. As a first step, qualitative erosion maps were drawn up. Studies underway are directed at quantifying the various processes of erosion, in order to select the type of anti-erosive treatment most suited to a particular site.

2.2 Wind Erosion

Erosion by wind also is common in the region and is further aggravated by the fact that strong winds blow from both the north and the south. Southerly winds are particularly harmful, as they have high speeds which allow them to mobilize and transport substantial quantities of fine surface soil elements from the arid and semi-arid areas in the south. In Algeria, wind erosion is especially a major problem along the coastal region on the plateau and in the steppe zones. In Morocco, strong winds blowing from the Atlantic Ocean have inhibited the development of many agricultural crops. In Tunisia, wind erosion is a very serious hazard throughout the country.

The most important factors of land use which contribute to wind erosion are: (i) cultivation of unsuitable land; (ii) use of power equipment (disc) for soil preparation; (iii) overgrazing and (iv) stubble and vegetation burning.

2.3 Desertification

Desertification, as discussed in this paper, refers to the decline of soil productivity as a result of unwise land use practices under the marginal climatic and edaphic conditions prevailing in the southern parts of the region.

In Tunisia, it is estimated that 18 000 hectares of potentially productive land are lost to the desert each year. Although similar data are not available in Algeria and Morocco, the areas of land lost are no doubt equally impressive.

3. SOIL CONSERVATION METHODS AGAINST WATER EROSION

The methods of controlling erosion caused by water commonly used in the region can be divided into three broad categories: reforestation; proper tillage practices; and the use of mechanical structures which control the velocity and volume of flowing water.

3.1 Reforestation

Many watersheds in North Africa lack a good vegetative cover. Efforts to re-establish a vegetative cover have been focused mainly on forest tree planting. The objectives pursued were not only to combat erosion but also to meet the local demands for firewood, charcoal, poles and timber. There have been many reforestation projects, covering the whole range of soil, climate and vegetation types.

The lack of precise information on suitable species and reforestation practices has led to the extrapolation of afforestation results from one country to another. The extremely interesting results of *Eucalyptus gomphocephala* and *E. camaldulensis* plantations in the Mamora in Morocco, for example, have generated considerable enthusiasm for large-scale use of these species under a variety of soil and climatic conditions. However, these species were not successful when first introduced in Tunisia. These early poor results underscored the need to carry out investigations on suitable species and to find most appropriate techniques for afforestation.

But reforestation as it was practised did not provide the protection needed. The areas reforested were generally very limited; in addition there were numerous failures in many plantations. Where the natural maquis vegetation was removed for the purpose of planting trees, erosion increased.

Because of these technical difficulties, the high cost of reforestation for erosion control and the low productivity of the trees, it has been accepted that reforestation should not be viewed as a "cure-all" solution for erosion, but should be used only for selected sites and often in conjunction with mechanical or other measures.

3.2 Tillage Practices

Tillage practices used for controlling erosion by water on arable land include: (i) contour ploughing, (ii) crop rotation; (iii) mulching; and (iv) strip cultivation.

Contour ploughing is one of the early practices which has been recommended for all lands with a slope equal to or exceeding 2%. This practice involves ploughing on the contour, making a deep furrow every 30 to 40 metres. When this is done, there is normally a significant decrease in soil erosion. Although highly efficient and economically sound, this technique has often been neglected and cases of ploughing up and down the slopes still abound. Algeria, Morocco and Tunisia have enacted legislation, organized campaigns and issued numerous publications to promote contour ploughing.

Crop rotation is known as a practical method to improve soil fertility and, consequently, to increase soil resistance to erosion. Grain fallow is the common practice. In the wet zone the ratio grain/fallow is around 4. The grain crops mostly used are soft and hard wheat. In marginal lands this ratio is reversed and the main grain crop is barley.

The so-called 18 months bare fallow has been a common practice in Tunisia to increase soil moisture. This involves ploughing of the land during a given summer, followed by two other ploughings - in the spring and the next summer. The area is then ready for seeding in the fall. However, this technique has resulted in a considerable increase in soil erosion and has been recently discontinued.

At present, the tendency is to use a short fallow period and to replace the fallow with a forage crop consisting usually of a mixture of legumes and grains (Viscia-Avena).

Mulching is a technique which has been used primarily to reduce sheet erosion. After the grain crop is harvested, the land is loosely ploughed and the stubble left. The standing stubble serves to dissipate the energy of the torrential autumn rains and to provide a rugged surface to keep the soil in place. With increasing animal pressure and the introduction of the practice of stubble grazing, this technique has unfortunately been discontinued.

Strip cropping is applied in areas where contour ploughing has been judged insufficient to control erosion. The type of strip cropping mostly practised is a strip of grain alternating with a strip left fallow or planted to a summer crop. Usually strips are 20 to 30 metres in width, with a deep furrow dug in the middle. The furrows are intended both to materialize the strips and to store rainwater. But while one basic requirement of strip cropping is the exclusion of grazing, this condition is not usually met and as a result this method is not highly efficient.

The above are but a few of the tillage methods which are known but only sporadically practised in North African countries. These methods are notable for their easy implementation, their efficiency in controlling erosion and the low cost involved in their execution. It is unfortunate that these useful techniques are not used on a wider scale in the three countries.

3.3 Mechanical Structures

There are several types of mechanical measures which have been used for erosion control in the region. These measures include bench terraces, small walls, and terraces.

Bench terraces are constructed along the contour of a hillside and designed for intensive cropping. The basic concept was first initiated by the Romans and found widespread application throughout the entire Mediterranean region. When bench terraces are constructed, the slope is modified and this results in a decrease of soil erosion. Erosion, however, is not completely prevented, as run-off still flows down the slope. Because of their high cost, construction of bench terraces is at present largely confined to heavily populated, mountainous areas.

Small walls of loose stone installed along the slope are designed to break the velocity of run-off water and to arrest the silt loads which accompany run-off. As the depth of silt deposit rises, new stones are added to raise the height of the wall, which ultimately leads to the formation of a level terrace. As in the case of the level terrace, erosion is only reduced, not completely stopped. In bare and stony mountainous areas, a slight modification of this structure, consisting of a simple arrangement of horizontal rows of stone along the contour, was found highly efficient for improving range lands.

Smaller terraces ("banquettes" in French) are the most recent type of mechanical structure which has been used intensively throughout the entire region. A terrace is basically a channel and a ridge constructed along the contour of the hillside and designed to store run-off (retention terrace) before it attains erosive speeds or to divert run-off (diversion terrace) to natural waterways.

The theoretical concept of diversion terraces, based largely on US soil conservation techniques, was studied by Saccardy in Algeria (Saccardy 1950). The design of such structures was based on the following assumptions: (i) a rainfall intensity inferior or equal to 3 mm/min; (ii) a run-off coefficient inferior to 1; (iii) a relatively dry soil; (iv) increasing infiltration rate with decreasing slope.

The vertical interval (H) between two succeeding terraces is determined by the slope using the following formulae

i. $\frac{H^3}{P} = 260 \pm 10$ for slope up to 25%

ii. $\frac{H^2}{P} = 64$ for slope greater than 25%

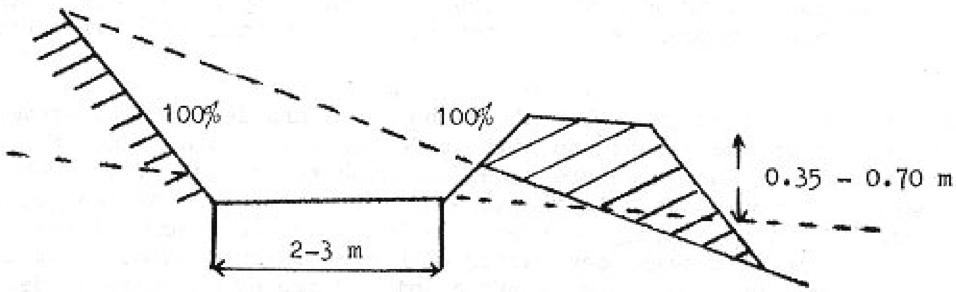
where: H = vertical interval in metre
P = slope in percent

Both formulae are used in Algeria and Morocco. In Tunisia, Bugeat developed a similar equation for all types of slopes in which $H = 2.2 + 8\ P$.

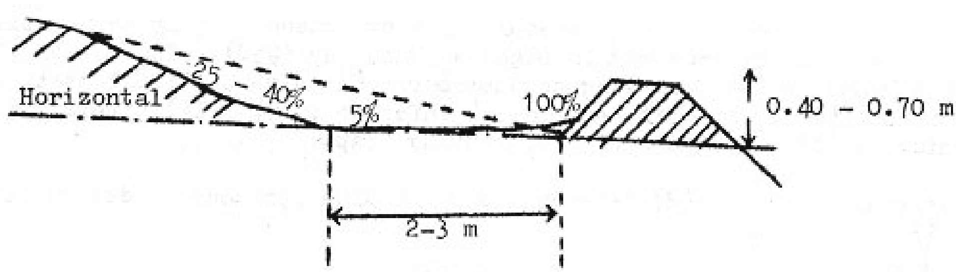
For the construction of terraces, specification tables were drawn up assuming a rainfall intensity of 3 mm/min and a speed of flow in the channel varying between 0.65 m/second and 0.80 m/second.

Depending on the slope and the envisaged crops, the cross-section varies from a simple normal profile to a broad base profile (Figure 1). Planting of forest, fruit and forage trees is done on the edge of the terrace while grain or forage crops are cultivated in the inter-terrace area.

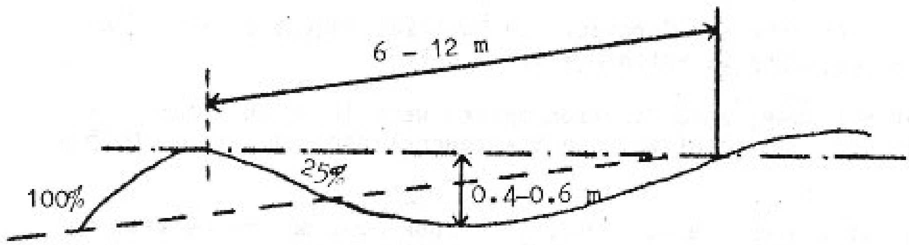
But the construction of terraces as practised in these countries is not usually in conformity with the basic technical requirement governing the function of these structures in relation to decreasing soil erosion. While, for instance, one basic requirement is to avoid clayey soils, such a requirement was seldom observed. Cases of retention terraces which are mostly constructed on this type of soil are notorious. Sometimes the need to build these structures is not dictated by an apparent erosion problem but decided for social reasons requiring creation of job opportunities. In other instances there was a lack of a better tecnique which could replace the terrace.



a. Terrace with a normal profile (French: "banquette à profil normal")



b. Terrace with inclined upward slope (French: "banquette à talus coupé)



c. Terrace with a broad base profile (French: "banquette à simple courbure")

Fig. 1 Types of terraces

Investigations in Morocco have raised questions on Saccardy's hypothesis on which the design of terraces is based (Heusch, 1970). Diversion terraces which channelize the run-off water into waterways were found to increase the rate of flow and to decrease the time of concentration. It does not seem, all factors considered, that the efficiency of these structures was carefully studied before their wide-spread application.

Retention terraces have resulted in an increase of pressure on the retention site which was accompanied by landslides and generated gully erosion. In the Pre-Rif region in Morocco, about 60% of the retention terraces have been destroyed, 40% of these by gully formation and overflow, while 60% were sliced down as a result of pressure increase (Robert, 1970). In this area it was found that retention terraces were not only inefficient but also harmful. In Algeria, the construction of terraces over 20% of the Fodda Watershed did not result in any decrease of erosion. In Tunisia, where such structures have been used intensively, it was found that in most cases the rate of erosion had increased. On the clayey soils the cases of failure were numerous.

3.4 Physical Structures to Control Erosion on Streams

These structures consist mainly of checkdams, which are constructed in waterways originating on steep slopes. Their purpose is to reduce the velocity of the water and to arrest the silt which comes with run-off. Both loose and masonry dams are used. When these structures are carefully designed and constructed they result in a great reduction of erosion. They have not, however, received sufficient attention in soil conservation projects.

Intensive erosion studies in Morocco have shown that the major sources of sediment were not the basin *per se* (where terraces were constructed), but the waterways and stream-banks which were enlarging at an alarming rate as a result of inappropriate land use in the basin. The present tendency is toward a better consideration of channel areas. In Tunisia, this has led to the investigation of suitable biological measures.

4. THE INTEGRATED APPROACH

Until recently the above, purely technical, measures for controlling soil erosion were considered in isolation and no attempt had been made to integrate them properly into a coherent watershed management programme. There have been some dramatic changes in watershed management policies of a positive nature, although in terms of implementation nothing has yet been done. The soil conservation programmes are to focus on the definition of new systems of land use better adapted to the real soil capabilities and geared to improving the economic conditions of the watershed population and solving the ecological problems. In Tunisia, the programme takes the form of an "integrated approach", where the basic principle is to replace "harmful activities" with "non-harmful" activities. This includes the replacement of wheat cropping on high slopes with permanent pasture, the planting of fruit trees on favourable soils, creation of fodder reserves, treatment of degraded lands and waterways, creation of new forage resources outside the watershed, increasing the agricultural productivity downstream, regrouping the watershed population into new communities with a social infrastructure and agriculture possibilities. Such an integrated approach, although attractive, is encountering several difficulties: (i) difficulties in changing the land use system; (ii) the time needed for tree planting to be economical; (iii) the difficulty of stabilizing the animal population; (iv) land tenure problems and (v) the need for more competence than that generally required for the construction of physical structures and tree planting. It will take a lot of time and cost a lot of money before such integrated programmes can be efficiently implemented. The present tendency is to focus on small-scale projects carefully selected among a large spectrum of priorities, implemented in close cooperation with the local people. The Derro project in Morocco and the Ouarra and Zeroud projects in Tunisia are typical examples.

5. MEASURES TO CONTROL WIND EROSION

These measures include shelterbelts, which reduce wind speed on farmlands, and vegetative devices, to stabilize sand dunes.

Control of wind speed, through the establishment of a vegetative or physical barrier, has been known and practised throughout the region, although in terms of implementation of a rational network of shelterbelt systems, little has been achieved. Nonetheless, timely actions were undertaken in three countries, focused essentially on the protection of small groves of fruit trees (citrus, in particular). This involved the establishment of a system of shelterbelts. These shelterbelts were usually very dense. In Tunisia they are suffering severe insect attacks.

A more recent effort in southern Tunisia was the experimental shelterbelt project installed on 200 hectares of farmland and designed to slow down the dessicating summer wind blowing off the Sahara. A second objective is to produce rural wood supplies. Two types of shelterbelts were tested: (1) perimeter windbreak which consisted of two interior rows of "fast" growing eucalypts (E. brockwayi, E. salmonophloia, E. occidentalis) flanked on each side by two slow-growing eucalypts (E. torquata, E. campaspe, E. oleosa, E. salubris, E. sargentii) which were in turn flanked by two rows of slow-growing acacias; (2) an interior windbreak which consisted of a single row of poplars spaced approximately 4 metres apart. Although the shelterbelt design and the species employed were not the best for such multiple use purposes, the feasibility of developing rural wood supplies was demonstrated.

To the south of the Atlantic coast of Morocco, some 200 000 ha have been treated by planting E. gomphocephala in the form of isolated blocks in small farm holdings. The result is a half-wooded landscape which apparently has resulted in a significant decrease of wind speed. Planting was carried out by the farmers themselves, who realized an economic return by selling Eucalyptus logs for making fish boxes.

Examples of shelterbelts on pasture lands are very rare. In the central part of Tunisia a few hundred hectares have been protected with a network of shelterbelts and this has resulted in a significant increase of forage production. Similar work was carried out on 900 ha of the Doukhoulas rangeland in Morocco, which generated considerable enthusiasm by pastoral tribes in view of the interesting results obtained.

For sand dune stabilization, the technology evolved in the three countries is based on the conventional method where hedges of dead shrubs are established in a checkerboard pattern and the space between the hedged plots is covered with a vegetative mulch. Later the plots are planted with coniferous trees (Pinus pinaster, Pinus pinea) or Acacia species (coastal dunes). Where the object of stabilization of continental dunes is to provide protection to oases, human dwellings and roads, sand dune barriers or artificial hedges of palm branches are erected every 200 to 300 m. As the dune barriers rise and cover the branch hedges, new branches are added to raise the height of the dunes. In areas where palm branches are not abundant, corrugated asbesto-cement sheets are used. These are also raised as the dunes rise. Other techniques for sand dune stabilization involving the use of chemical emulsions (petroleum by-products, rubber emulsions, lignin materials) have been tried throughout the countries with a varying degree of success. In general, the traditional method appears to be the most reliable one, but it is labour-intensive and requires considerable quantities of dead material. In Tunisia, nylon nets have been used experimentally to stabilize dunes in the Douz region. The area in between the dunes is planted with drought-resistant species.

6. MEASURES TO COMBAT DESERTIFICATION

Desertification is a hazard whose potential has only recently been comprehended. Early efforts focused on carrying out small-scale activities such as tree planting, creation of fodder reserves and sand dune stabilization. In Algeria a solution was sought through the creation of a "green belt" in the southern part of the country. This green belt with a length of over 1 000 km and a width of 10–15 km was intended to arrest the northward advance of the Sahara.

Another approach considered throughout the three countries is rational management of the lands threatened by desertification. Planned actions are the improvement of range land and livestock production. Most efforts are directed toward the development of technical information for the implementation of these programmes. Important projects are the integrated project in the Wilaya of Saida in Algeria, the management of rangelands in the pre-Saharian zone in Morocco and the Oklat Marteba project in southern Tunisia.

7. CONCLUSIONS

Soil conservation practices in North Africa have been focused mainly on corrective mechanical measures, which in most cases have been insufficient or not suitably adapted to counter erosion problems. Despite the fact that the three countries discussed in this paper have launched large soil conservation projects, much still remains to be learned, both in terms of basic scientific facts as well as consideration of the plant species which may be used for the restoration of eroded sites. No one seems to have an intimate knowledge of the successional capacity of the native plant cover which can be used to rehabilitate degraded land. There is only scant knowledge of the effectiveness of different plant covers, soil preparation methods, engineering techniques or combinations thereof for controlling erosion. Terraces are not a cure-all for every degraded watershed, particularly on badlands and clayey soils. Biological measures need greater consideration. The economics of the various conservation measures are in need of much better quantification. The socio-economic framework that has given rise to destructive land use in the countries has not been fully taken into account.

As regards wind erosion, existing knowledge is based on studies and research mostly carried out outside the region. Because such studies have not been replicated and their results confirmed, wide gaps exist in our current knowledge.

Dune control efforts to date have largely been on the basis of trial and error experiences at a few locations within the countries. Not much is known about the plant-sand-water relationships and other physiological questions. Little information is available on hydrology and groundwater vis-à-vis dune afforestation. Would thirty-year old plantations on dunes begin to "mine" all the capillary water and groundwater and then begin to die off?

This lack of knowledge is not simply an academic concern. There are soil conservation and dune afforestation schemes in these countries dating back thirty years, some succeeding and others failing, but without explanation of why. While the present trend is toward better management of the natural resources, there are no guidelines of an integrated nature which can be used to assure the long-range success of land management programmes now under way. Only when we better comprehend erosion problems and their processes will we be in a position to provide practical field guidelines and the technical training for suitable land protection and management.

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C. Grassland Management

Paper No. 11 SOIL AND WATER CONSERVATION AS AN AID TO RANGE MANAGEMENT

by

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The UNDP/FAO Rangeland Conservation and Development Project was a multi-disciplinary effort using experts in soil and water conservation engineering, agronomy and range in order to "investigate all means of reversing the trend of steady deterioration of the productivity of the rangelands and coordinating programmes and activities, which will result in the best use of the vegetation, livestock and water resources". Short term objectives of the project, in the north, were "to have emphasis on soil and water conservation measures". 1/

Northern Somalia consists of a long, relatively narrow (200 kilometers) strip of land facing northward toward the Gulf of Aden, with its back toward the Ethiopian highlands. The upland plateau which extends into Somalia from Ethiopia is a gently undulating upland of deep, redish, loamy soils partially derived from alluvium and partially derived from residual material. Occasionally, especially in the west, the sharp peaks of partially buried mountains extend above the soil surface. The plateau extends northward to a fault zone which forms a narrow, rocky, mountainous belt. This belt of mountains ends abruptly at a north facing block escarpment which rises some one thousand meters above the sandy coastal plain. This plain slopes gently from the foot of the escarpment into the Gulf of Aden.

The area of highest average annual precipitation is the mountainous belt just south of the escarpment, which receives a mean annual rainfall between 650 and 750 mm. This area of highest precipitation is small, there is little soil on the steep slopes, and little of the precipitation is retained where it falls; therefore the belt has a small productive potential for livestock.

The area of second highest mean annual precipitation, 400 - 650 mm is the plateau area between the mountains and the Ethiopian boundary, and extending westward from Hargeysa to Borama, an area of good soils and high production. From Hargeysa the mean annual precipitation decreases eastward both on the plateau and on the coastal plain until a mean annual precipitation of only 50 - 150 mm is received on the eastern coastal plain.

The most prominent physiognomic feature of the vegetation is overuse by livestock. Otherwise the vegetation is open savanna with evergreen Commiphora and Balanites trees and shrubs within the mountainous belt; deciduous, thorn-tree savanna on the upland plateau; and on the sandy plain there is an Acacia shrub and low evergreen Balanites obcularus tree savanna with coarse bunch grasses.

It is seen that the entire area of northern Somalia falls within what must be classified arid land. The humidity is, however, generally quite high, 60-70 percent which reduces the evaporation and transpiration stress and makes early morning dew a common phenomenon.

1/ Project Document number SOM/72/003/E/01/12, 11 June 1974

The people of northern Somalia are traditionally livestock owning, herding people who have specialized in sheep, goats and camels. These animals can be independent of water for one and two weeks and thus the people could in the past move over a relatively large area with their livestock. This mobility plus a low rate of population increase in both people and livestock was an adequate management practice. The increase in technology and the resulting increase in population growth rates, in both people and livestock, coupled with the loss of land for other uses has caused the traditional management practices to break down, and as yet no formal management system has been substituted for the traditional practices. The results have been overuse of all of the rangelands.

The effects of overuse by livestock is reflected throughout northern Somalia in the eroding soils, the areas of erosion badlands, and the areas of bare soil. Such badly eroded areas may take up as much as 20% of the total range area.

It was these unhealthy symptoms which stimulated the Government to request aid and the result was the Rangeland Conservation and Development project.

In response to the stated short-term objectives of the project, the project personnel in the North chose several sites for development. This development included water conservation bunds for ponding water in order to increase available soil moisture. The improved moisture conditions will increase fodder production on the site. The structures also decrease soil loss due to water erosion. Some of the sites required construction of dams and canals that will divert spate water from a stream course into the modified area. At other sites it was only necessary to slow and spread the runoff water from the adjoining hills. For either method, development requires money, materials, equipment and time. These requirements make the soil and water conservation sites expensive.

Due to the high costs required to develop these sites, it would seem that only a small percentage of the total range area can ever be developed for increased fodder production. Because the site must be limited in size but will have a relatively high production of fodder resulting in a valuable supply of hay to be harvested and used or sold, some critical questions may arise concerning the use of the site such as: 1) who owns the site; 2) who controls the site; 3) how is the site to be used; 4) who owns the harvested hay; 5) whose livestock gets the hay; 6) how are these sites to fit into the overall programme for improvement of range condition. All of these questions came up during the time the project personnel were developing sites.

The variety of answers possible to the above questions uncovered some problems which may serve to emphasize the need for studying the local situation prior to, or in conjunction with, the preparation of the project document.

The human population in the project area should not be overlooked. Through Government representatives, meetings should be held with the people to seek local acceptance of the project. If necessary, a serious pre-project phase of education and extension work, to obtain involvement and cooperation of the local people with the project, should be carried out. The personnel of the concerned Government ministries and the proposed project counterpart should be involved in this pre-project exercise.

Continued support of the project by the Government is absolutely necessary. Government support at the highest level may be obtained by intensive discussions during the planning stage and, if necessary, a series of meetings with field trips to the project area may be made during the discussions. Government officials and personnel should know what results to expect from the project and what steps are necessary to achieve these results. A schedule for the expected results should be included in the document.

All previous reports, publications and documents relating to the project area should be obtained and made available to the international personnel of the new project. This is to ensure that all possible climatic, edaphic and hydrological data are studied so that engineering-hydrological designs and field lay-outs of any physical structures are adequate for the environment.

In order for projects of this kind to be valuable and effective, soil and water conservation measures must be combined with adequate control of people and livestock in order that the range and watershed may be improved. Any improvement in range condition requires proper range management. Proper range management requires the agreement and cooperation of the livestock owners who are using the range.

There is now a combination of several conditions which can make it possible to settle the nomadic people of northern Somalia and thereby make it possible to control the livestock and manage the range. One of these conditions is the ability to have these improved soil and water conservation sites. Another condition is the desire of the Government and the people to have the transhumant population settled.

The Government wants to settle the people so that they may be governed. The transhumant people wish to settle because they have no real legal rights now; they are losing their best lands to other uses and other people; the people wish to have their children attend schools; the people wish to have access to medical attention and medicines; they wish to be near water and trading areas. The livestock owners are well aware of the deteriorating condition of the range.

One way to settle the people is to organize them into ranch cooperatives. Three types of cooperatives are needed to provide for the different conditions in northern Somalia. One type of cooperative is the stock raising cooperative where members are pastoral or nomadic people. A second type is the town or village cooperative whose members will be the livestock owners who live in the villages and towns and whose livestock forage in and around these urban areas. A third type is a holding ground cooperative whose members are traders who buy the exportable animals from the livestock raising people and sell to markets across the Gulf of Aden.

All three types of cooperatives will be centred around one or more soil and water conservation sites where the relatively high yield of forage will be harvested for drought reserve feed, supplemental feed and, in the case of the stock raising ranch cooperatives settlement sites, family gardens for the people. Each of the soil and water conservation sites will be surrounded by or adjacent to, sufficient rangeland to support the range animals, plus an additional amount of range sufficient to allow one fourth of the range to be unused. The rangeland will be divided into four units, each of which will receive two years consecutive rest out of each eight year cycle. There exists good evidence that this type of management is sufficient to change the deteriorating condition of the rangeland into an improving condition through restoration of healthy root systems and vigour to the forage plants.

The work of developing the soil and water conservation sites and the additional stock water improvements will be done by the cooperative members largely with hand labour.

This project has organized seven cooperatives consisting of 322 families. There are six more cooperatives (494 families) awaiting Government final approval (a law is being considered). We have more than 100 applications from other groups. There is now support for these cooperatives from the nomadic and semi-nomadic people and from the Government at the local level. Continuing technical help is urgently needed.

Paper No. 12

GRASSLAND MANAGEMENT IN RELATION TO SOIL CONSERVATION AND EROSION CONTROL IN DEVELOPING COUNTRIES

by

T. Ionesco 1/

1. FOREWORD

It is unanimously recognized that the erosion problem is more acute in arid and semi-arid zones than in the temperate and tropical because of climatic, soil, land use and other conditions, and the lower average amount of ground cover in the arid environment tends to aggravate the situation. Many of the developing countries are located entirely or partially in the arid and semi-arid zones.

In other respects, it is also recognized that the rangeland areas - which provide the principal feed resource for livestock production - cover the largest part of the arid zone. Nevertheless, these rangelands are misused by overstocking, clearing for cultivation, burning and removal of woody species for firewood, charcoal or distillation, etc. and this results in degradation of the plant cover, increased erosion, reduction in production and in productivity of rangelands, etc. As populations expand and feed demands increase as well, the improvement and better management of rangoland in order to maintain or even increase livestock production is indispensable. From our point of view, this is the main goal to attain, except for the too degraded areas where the first priority is the reestablishment of vegetative cover for soil conservation.

Thus soil conservation and erosion control in the productive rangeland areas are not activities *per se*, but the particular consequence of rangeland and fodder crop management. Of course, some exceptions exist in some critical areas.

2. POTENTIAL AND PROBLEMS IN EROSION CONTROL BY GRAZING LAND MANAGEMENT (in Mediterranean zone)

As mentioned, most of the arid and semi-arid rangelands are now degraded or eroded. As regards potential and technical improvements, it is worth taking into account three main zones:

- semi-arid, receiving more than 400/350 mm (mean annual rainfall). The isohyets from 350 to 400 mm correspond to the northern limit of the steppe vegetation and to the southern limit of regular and productive cereal cultivation under dryland farming conditions;
- arid, the average annual rainfall varies from 100 mm to 400/350. The 100 mm isohyet is the extreme southern limit of non-irrigated agriculture;
- desert, below 100 mm.

1/ Technical Officer Crop and Grassland Production Service

2.1 The semi-arid zone

The main pasture resources in this zone concern:

- natural rangeland, particularly forest degraded formations, such as matorral, garrigue, maquis, sward, etc.

- forests (Topic C)

- sown pastures and permanent swards, fallows...

- fodder crop cultivation.

Although degraded, the natural rangeland potential is still high and pasture rehabilitation, soil conservation and erosion control can be realized through technical improvements such as: range development, rotation and/or deferred grazing adapting stocking rates to carrying capacity; establishment of grazing reserves, etc. In some parts of the rangelands erosion can be easily controlled by planting adapting species, particularly fodder crops such as bushes or perennial grasses and legumes, Opuntia ficus-indica, Atriplex nummularia, Acacia cyanophilla, Festuca elatior, Hedysarum coronarium, Phalaris truncata, Pennisetum ciliare, Pennisetum clandestinum, Panicum antidotale, Orysopsis miliacea, Dactylis glomerata, Lolium perenne, etc.

Concerning the sown pastures, permanent swards and the fodder crops in cultivation areas, no specific rangeland techniques exist, except respecting the rangeland livestock management calendar.

On the whole, as regards rangeland and the fodder crop potential of this zone, there is no particular problem with soil conservation and erosion control apart from application of the usual management techniques. It is here that improvement both in the agronomy (seeding and planting) and animal management can show the best gains.

2.2 The arid zone

In this zone, the main pasture resources concern:

- natural rangeland formation (steppes)

- fallows

- fodder crops under irrigation.

As is well known, the rangelands are now degraded, but except for some irreversible areas - completely desertified - the possibilities for improvement are real and important. Nevertheless, the chances of successful establishment and persistance of sown pasture and fodder crop cultivation in dry farming are scarce and the operation is not generally recommended except on fallow lands. Pasture rehabilitation, soil conservation and erosion control can be carried out through rotational and/or deferred grazing and adapting stocking rates to the long-term carrying capacity. On the other hand, the establishment of fodder reserves (Opuntia, Atriplex, Acacia, Prosopis, etc) is possible (soil conditions being favourable). At the same time, these reserves can be utilized as soil stabilization species. In this latter case, as regards their consumption by the animals, zero grazing is recommended, or cutting feed and keeping the animals outside these fragile areas.

Concerning the irreversible degraded zones, the re-establishment of a vegetative cover, as regards soil conservation and erosion control, can be carried out by using current techniques without taking into account the rangeland problems before obtaining a successful result. But the use of certain fodder species is also recommendable.

In some countries, the combination of pitting, terracing and water spreading have been very beneficial in restoring vegetation cover both with and without seeding. It should be useful in developing countries.

3. SUMMARY

The two most critical problems of arid and semi-arid rangeland regions are:

i. the general overstocking and complete lack of any form of animal manipulation with a view to forage management - coupled with the well-intentioned development of water for various reasons, but the lack of implementation of a corollary grazing management programme has further compounded and spread the adverse effects of overstocking;

ii. the pressure of human populations which is causing rapid expansion of cultivation into the rangeland areas, especially on the semi-arid/arid fringe. This further restricts and compounds the grazing land management problem and adds to deterioration of the feed resources for the animals. In addition, the problem becomes much more serious when the cropland fringe is pushed beyond the climatic margin of economic production for crops and when particularly fragile soils are cultivated or tilled with inappropriate techniques one of the most critical needs is for comprehensive ecological and land use surveys that will provide essential information to guide these kinds of necessary expansion programmes and gives a guide to the rangeland areas that can be improved to compensate the loss of land for livestock use.

The problem is not all that hopeless because throughout the arid and semi-arid regions of the world, particularly the latter, grazing management experiments and demonstrations as well as a few large operating ranches have demonstrated that natural plant succession under proper animal management (application of principles of proper stocking, off-take, season, frequency and intensity of grazing use with, often, some simple scheme of rotational management) can remarkably improve the potential of many ranges considered to be irreparably degenerated. Agronomic range improvement is another tool that can often provide the flexibility required to institute improved animal management on remaining rangelands. Similarly more work and application is needed in areas of long term fallow to work forage and fodder crops into the food-crop rotations and to use adapted grass-legume on the fallow lands (where fallowed from 2 to 7 or more years). This not only stabilizes the soil and improves fertility and soil organic matter, but provides an important forage reserve.

Paper No. 13 RESEARCH NEEDS FOR SOIL CONSERVATION IN DEVELOPING COUNTRIES

by

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1. INTRODUCTION

1.1 Pure or applied research

The conventional approach is to divide research into pure research and applied research. I would like to suggest that for soil erosion and soil conservation a better division is into subjects which have general or worldwide application, and those which have local application. This is perhaps not really a different approach, because the topics of universal interest are mainly concerned with understanding the basic principles and processes of erosion and so they are fairly close to the concept of pure research, while the localized interests are more concerned with solving local problems and so are closer to applied research.

The purpose of this paper is to review the present state of knowledge and hence to identify weaknesses or deficiencies which can indicate research needs. In trying to arrive at priorities for research which should be incorporated into an action programme it may be helpful to keep in mind this difference between "pure" studies of worldwide principles and "applied" studies of more localized solutions to local problems.

1.2 Assessing the extent of erosion

In recent years the urgent need to increase food production has focussed attention on soil erosion, to the point where almost all governments and states are aware of the problem, though whether any of them are tackling the problem adequately is much less certain. When looking at the extent of soil erosion and deciding how bad it is we might consider two points.

1.2.1 Exploitation or Development?

We must be careful to differentiate between "exploitation" in the sense of the unwise consumption of non-renewable resources, and legitimate exploitation i.e. the sensible development of resources. No-one criticises the oil-rich states of the Middle East for exploiting (i.e. developing) their oil and pouring the income into the development of a long-term agricultural industry. Is the situation really so different when a South American country like Brazil deliberately exploits its land resources for coffee production? or Argentina through meat production? and uses this to generate national wealth or to create an industrial society or even for education?

1.2.2 The danger of exaggeration

It is easy to be carried away by the "awfulness" of erosion as seen through the eyes of the specialist. A classic example is Lesotho, formerly Basutoland, in Southern Africa, where before 1900, the first white settlers reported on the "almost total destruction of the land through over-grazing". In their classic survey of worldwide erosion, Jacks and White (1939) said the same, and every 10 or 15 years a report on erosion in the country predicts immediate and total disaster. It is quite true that the gullies are appalling, and the soil loss and the silt load in rivers extraordinarily high, but the cattle are still fat and the people appear to be thriving and reasonably fed. Surely it is a contradiction for "disaster" to be a stable state of equilibrium.

1.3 Assessing the effectiveness of soil conservation

Unfortunately few reliable and quantitative surveys have been made of the effectiveness of national soil conservation programmes. The most thorough is naturally in the USA, where Held and Clawson (1965) attempted to review the success of the USDA SCS since a national survey in 1934 showed the alarming fact that roughly three-quarters of the arable land of the US was seriously damaged by erosion (Bennett, 1939).

A simplified summary of Held and Clawson's conclusions is that in the United States, erosion has been just about held in check, and if that is the result after a generation of work by the most sophisticated conservation service in the world what hope is there in developing countries where the problem is so much greater but the capacity to operate a conservation service is so much less?

It is relevant to consider, when looking at deficiencies and needs, how much the need is for technical solutions, and how much the problem is to learn how to apply the already known solutions. Another provocative thought is that if the known solutions are not being applied, then they must by definition be not the right solutions.

Quite apart from technical expertise many other factors may be the limiting constraint on effective soil conservation - for example, the availability of money, or of trained personnel, or social, political, or legislative restraints.

1.4 The special problems of developing countries

1.4.1 Developing and developed countries

It is only natural that the developing countries should look to the developed countries for a lead in soil conservation, and particularly to the United States which has led the world in this field.

However, the lesson of the development of conservation in the USA is that we should understand and appreciate the changing pattern there, but not necessarily follow it, at least at the moment. Most developing countries are on the whole at the point which the United States reached in the thirties and forties, that is a rapid increase in the number of small tractors, and a requirement for maximum erosion control through mulching and terracing. The current trend in the USA towards much more sophisticated and expensive control measures results partly from the adoption of much larger machines (e.g. 6 and 8 row planters in the mid-west) and partly from the ability in the United States to invest massive amounts of capital in land manipulation, e.g. grassed-back bench terraces, designed to suit the large machines.

Another factor not reproduced in developing countries is that a high level of industrial development leads to a shift in emphasis from soil conservation to water conservation. Far more effort is now devoted in the United States to the effective use of water and the control of water pollution, than to soil conservation. Most developing countries are fortunate in that this problem is not yet so serious.

1.4.2 Tropical and temperate climates

If the developing countries have less man-made problems, these are counter-balanced by the physical factors which lead to a greater erosion hazard in the tropics and sub-tropics than in temperate climates. In the tropics the topography is often more conducive to erosion (Bosazza, 1953) and the soils more vulnerable (Eden, 1964) and the rainfall more erosive (Hudson, 1976).

1.4.3 Land pressures

The density of population varies widely in developing countries, but one common factor is the rapid increase in population, which results in changing pressure on the land. The population density in the Sahelian region of Africa may be low in comparison with other regions, but a 50% increase in either human or cattle population is likely to cause dramatic changes at any level of land use.

Later, when discussing land selection and land classification we will consider the fact that a classification scheme may sensibly put land into the category "unsuitable for cultivation" when there is plenty of other land available. But in many countries all the gently sloping land is already used or over-used and this puts a different complexion on the issue of the slope limit at which cultivation should stop.

1.4.4 Unexpected byproducts of development

There are sometimes unexpected and undesirable side-effects of development projects which are themselves desirable. For example, the change from shifting cultivation to settled arable farming may lead to increased food production and higher income but at the same time cause increased erosion. Another interesting example is where the success of the campaign to eradicate cattle diseases in the Sahelian zone of Africa has led to such massive increases in cattle population that over-grazing is most alarming, and could lead to an irreversible change in the ecological balance (Ormerod 1976).

2. ANALYSIS OF THE SITUATION

2.1 The factors affecting erosion

Figure 1 shows one way of bringing together all the factors which determine how much erosion will take place in a given situation. When considering the state of knowledge it will be convenient to look at each of these factors in turn. We should also consider how much we can exercise any influence on erosion, and which of the factors can be modified.

2.2 How erosion can be controlled

In the case of rainfall there is clearly very little scope for manipulation or management. Some slight modification to rainfall patterns may be possible through cloud seeding or similar techniques but at present these are likely to be localized and of small consequence. For practical purposes erosivity can be considered as fixed; we can study it and measure it but we cannot change it.

The situation is very similar for erodibility. The inherent characteristics of soil such as the mechanical composition can seldom be manipulated sensibly or economically.

Some modification can be made to soil characteristics like tilth, or structure, or organic matter but such changes as can be achieved are all the result of management and can be considered under that head.

Topography can certainly be modified, and whether it is sensible to do so is a question of economics. If the cost-benefit ratio is right, the slope can be changed by bench terracing or the length by building channel terraces.

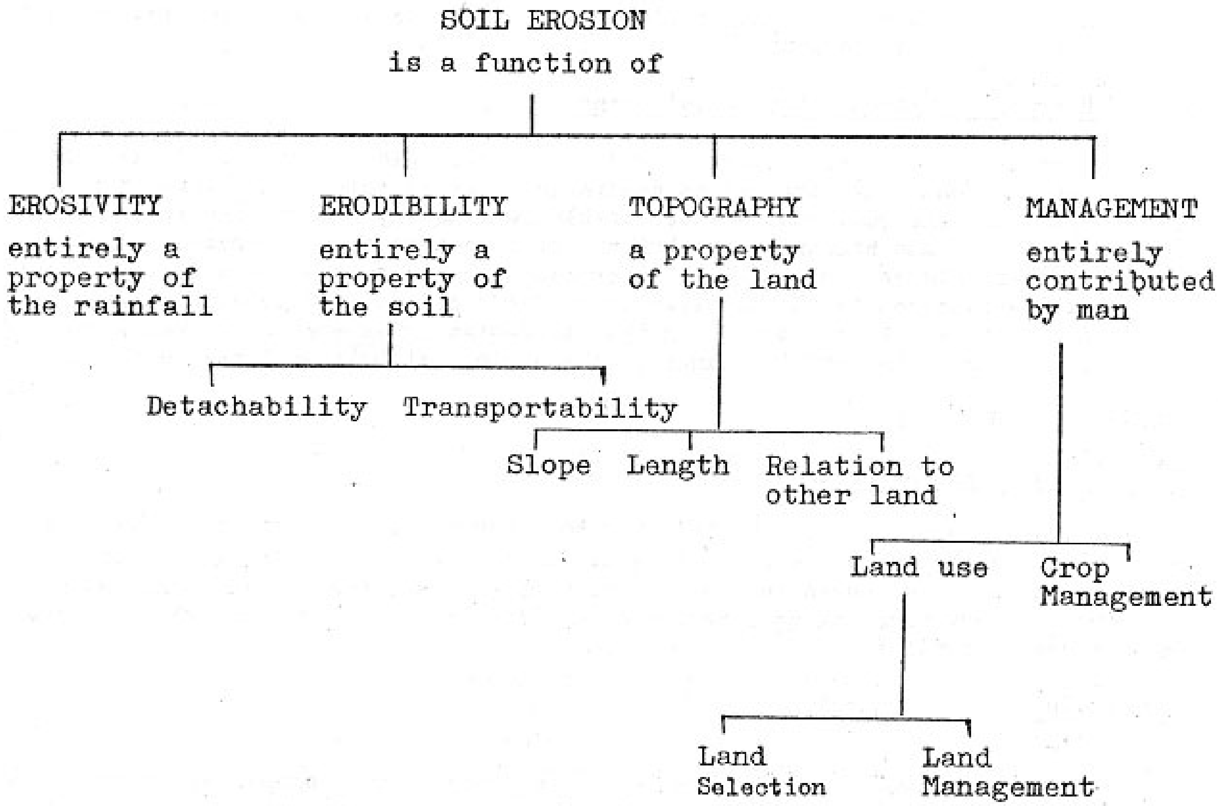

Fig. 1 Factors influencing erosion

However it is in the area of management that erosion can best be controlled, and the quantitative difference in amounts of erosion under different styles of management is very much greater than the difference resulting from variations in the other factors. Putting numbers to this concept, the variation in the erosivity within a country or from year to year might be in the ratio of 5 to 1. The effect of different erodibilities would be similar-ratios of up to 5 to 1. The effect of channel terraces is roughly to halve erosion, i.e. a ratio of 2 to 1. But different land and crop management techniques could result in the erosion changing by a ratio of 1 000 to 1.

2.3 Information needs

Whether or not we can do anything to change the pattern, we still need to know and understand the processes, so we need as much information as we can get about every aspect of erosion. But looking at the various factors which influence erosion we can see the significance of the division suggested in Section 1.1 between generalized or pure research, and localized or applied research.

In the case of erosivity and erodibility the questions to ask are: "What do we already know?" and "What do we therefore need to know?" The problems so defined will be of a general nature and any answers will have widespread application. A programme of research on these topics should therefore be worldwide and concerned with fundamentals.

When management is involved, as in land selection or modification, and crop management, the questions to ask are: "What is the present practice?" and following that, "Are the present practices adequate?" and if not, "how can they be improved?" These are essentially localized questions. The answers in one country may be quite inappropriate in another, and so research on these applied problems will have to be done separately for each different set of conditions.

3. THE EROSIVITY OF RAINFALL

3.1 Definition and application

The definition of erosivity is the potential ability of rain to cause erosion. It is a function of the physical characteristics of rainfall and it is known that the characteristics which are most closely related to erosivity are intensity and functions of raindrop mass and terminal velocity such as kinetic energy or momentum.

The ability to quantify erosivity has two main applications. If it is known that the erosivity in Region X is much greater than in Region Y, then recommended soil conservation measures can be designed accordingly. The other use is in research. The results from field plot experiments are much more useful if it is possible to calculate, and allow for, the variation which is due to the different erosivity of different storms or of different seasons. In laboratory studies and work with rainfall simulators, a quantitative measure of erosivity is essential if any precision is to be achieved.

3.2 Measurement of erosivity

Erosivity can be measured directly by observing how much erosion is caused by a particular storm or series of storms. This can be done by field experimental plots, but for many purposes it is simpler and more accurate to eliminate the variable soil factors like soil type, moisture, slope and crop which are nothing to do with erosivity and so can only confuse the issue. For the assessment of 'splashability', i.e. the ability to cause detachment, the method of Ellison-type splash cups is recommended. With developments in experimental technique (Bisal, 1950; Hudson, 1965) this method gives a simple but reliable and accurate measurement.

It is possible that there could be an interaction effect between erosivity and erodibility. In that case a measure of erosivity based on the ability of rain to cause detachment might not be the same as a measure of erosivity based on the ability to transport soil. However this is most unlikely. A carefully controlled series of experiments in Africa (Hudson, 1976 p. 68) showed that an equally precise correlation obtained between erosivity and erosion, whether the erosion was measured by splash alone, or by splash and run-off from Free-type soil pans, or by field erosion from experimental plots.

3.3 Indirect assessment of erosivity

If, instead of having to start taking measurements of erosivity, it was possible to calculate it from already existing rainfall data, this would greatly increase the available store of knowledge. It is exactly parallel to information on water evaporation - one can either measure it directly by setting up an evaporation pan, or one can make an estimate from existing data on temperature, humidity, etc. The catch is that all such indirect estimates are empirical, that is they use relationships which are created to fit observed data. The relationship can be expected to apply within the conditions of the data, but there is absolutely no reason why the relationship should be valid in other circumstances. Unfortunately this basic principle of scientific research is all too often ignored in the desire to extend the use of an empirical solution by applying it outside its limits.

We have today several alternative empirical methods for calculating erosivity from rainfall. The best known is the EI_{30} index (Wischmeier et al., 1958) in which soil loss from experimental plots was found to be well correlated with the kinetic energy of the storm E, and an arbitrarily chosen parameter I_{30}. There is no theory to explain why it should be I_{30} rather than I_{60} or the many other parameters tested. It was observed to give the best fit and that is all. Since I_{30} is a function of the kind of rain or type of storm there is no reason why the same relationship should hold for other rainfall patterns, and indeed studies have shown that the correlation is not so precise in the case of high-intensity tropical rainfall (Hudson, 1965). Another disadvantage of this index is that it requires the laborious extraction of data from automatic raingauge charts.

Seeking an alternative index suitable for Africa the author established $KE > 25$, that is the total kinetic energy of all the rain falling at intensities greater than 25 mm/hour (Hudson, 1965). Within the conditions of the experiment this was found to be very efficient and practical and it has the advantage of being more easily computed than EI_{30}, but again it is empirical, and in other situations there would be other parameters giving a better fit, and this line has been extensively pursued by Elwell & Stocking (1973).

Yet another formula has been developed using data from Nigeria by Lal (1976). That index is AI_mV where A is the amount of rain in a storm which has maximum intensity I_m, and V is an optional refinement allowing for the increased terminal velocity of rain accompanied by wind.

All of these methods depend upon calculations of erosivity for each storm and a summation to give an annual value. Long term average annual values can then be calculated if sufficient records are available. For research purposes the precision obtainable by separate calculations for each storm is desirable, but an annual index calculated directly from daily, weekly, monthly, or annual rainfall would be very useful. Estimates of annual erosivity have been derived from both daily and annual rainfall in Malaysia by Morgan (1974). The only such assessment in general use is the index $\frac{p^2}{P}$ (Fournier 1969, Low 1967) which gives a rough guide to annual erosivity from the relationship between annual rainfall P, and the rainfall in the wettest month p.

3.4 Research needs on erosivity

Although we have several usable techniques available they are all empirical and all have limitations. Clearly a search for a truly causative relationship is desirable. and is an area of basic or general research where a combined co-ordinated programme might be more effective than individual efforts. Plans for starting such a programme were made at the International Workshop on Soil Conservation and Management in the Humid Tropics, which took place at the International Institute for Tropical Agriculture (IITA), Ibadan in June 1975. This plan envisaged a worldwide network of stations which would operate a common programme of experiments on erosivity, using standardized equipment. One of the difficulties is developing suitable equipment. A form of splash cup will serve to measure splash erosion but we need a universally applicable device to record erosivity. At both the University of Ghent, Belgium, and the National College of Agricultural Engineering, England, studies are being carried out on instruments using the acoustic principle (following Kinnell, 1968; Forrest, 1970) and pressure transducers (following Kowal et al., 1973) to record the impact of raindrops.

In applied research at regional or local level there is a need for more studies of rainfall. In the past it was considered sufficient to record only the amounts of rain. For erosion research we need to know about erosivity, maximum intensities, intensity/duration relationships and frequencies of severe storms.

4. THE ERODIBILITY OF SOIL

4.1 Definition and application

The definition of soil erodibility is its susceptibility or vulnerability to erosion, that is to say the reciprocal of resistance to erosion. It can either refer only to the physical characteristics of soil, like texture and structure, or it can include management factors which can affect erosion, such as how the soil is cultivated. In this discussion the narrow definition will be adopted, corresponding with the K of the Universal Soil Loss Equation.

The applications or uses of a quantitative measure of erodibility are similar to those of erosivity. There is the practical application in the design of control measures which need to be intensified for a vulnerable soil or relaxed for a more resistant soil. There is also the use as a research tool where the ability to allow for variations due to soil erodibility allows us to interpret the effects of other variables.

4.2 Direct measurements of erodibility

If we subject different soils to the same erosivity and measure the soil loss, then we have a direct measure of erodibility. The problem is that we may get different answers according to how we measure the soil loss.

Today our thinking on erodibility has gone right back to Ellison's starting point of 30 years ago, and it seems unlikely that any one single measure of erodibility can account for the separate properties of resistance to splash (detachability) and resistance to surface flow (transportability).

There are other problems associated with direct measurement of erodibility. With field experiments under natural rainfall it is not possible to control the erosivity; with laboratory experiments the simulated rainfall can be controlled but the soil is not the same as in the field, and even in the best combination of a rainfall simulator used in the field, there is still the problem of separating out management effects like previous cropping practice.

4.3 Indirect assessment of erodibility

In view of these doubts about how erodibility can be directly measured it is not surprising that indirect assessments based on other measured characteristics have not been very successful. There is a vast literature on the subject which has been well reviewed, for example Bryan (1968), and a wide range of techniques have been developed since the attempts of the American soil scientists in the 1930s to correlate erodibility with simple factors like mechanical composition.

This approach to the subject received a great boost when Wischmeier produced empirical relationships, first using 15 factors (Wischmeier & Mannering, 1969) and later a simpler variation for practical application with 5 factors (Wischmeier, Johnson & Cross, 1971). However the point made earlier about empirical erosivity relationships applies equally here. The Wischmeier nomograph is derived from data on American soils and can be expected to work in the United States, but one cannot either assume or expect that it will be equally valid for different soils in the humid tropics or in arid regions, and indeed attempts to extrapolate it beyond the measured range have so far been disappointing.

4.4 Research needs on erodibility

The first priority would seem to be basic research on the fundamentals of erodibility. Can any single index or parameter adequately describe and quantify resistance to erosion? Or should the various components such as resistance to detachment be assessed separately, and then combined? Since this is long-term basic research which will have worldwide application it would be appropriate to mount a combined programme involving research workers in many countries.

At the same time, the long-term search for real understanding should not slow local attempts to find local solutions. In many developing countries a real step forward would be achieved by simple comparative studies of the relative erodibility of the major soil types. I suggest that current thinking would point to this being best achieved by rainfall simulators operated on field plots. Some standardization of technique is desirable,and the IITA 1975 conference considered this, but there is a gap here which needs to be filled.

5. EFFECTS OF TOPOGRAPHY

5.1 Slope

The effect of slope on erosion has been extensively studies and is well documented. Mathematically the relation is

$$\text{Erosion} = a\,S^{b}$$

where S is the slope expressed as a percentage, and a and b are constants. The value of a depends on many factors, mainly management of the soil, and b is an exponent which varies according to soil type and land use but is usually between 1.3 and 2.0.

The relevant question here is to what extent is it sensible to try to modify the natural slope. Because of the form of the mathematical relationship a reduction in slope will reduce the erosion more than the proportion by which the slope is reduced, but slope modification has three main problems.

a) Earth moving on a large scale is so expensive that it can only be justified in special cases. Some examples are ancient bench terrace systems which could be built because of slave labour, or modern bench terraces which have to be made because there is no alternative. Very high costs may be justified by expected high returns; e.g. large terraces in the United States to allow level operation of sophisticated machinery, or terracing for high-yield crops like olives, vines, fruit, or irrigated crops. In southern Czechoslovakia land shaping is being carried out on a massive scale with cuts of up to 10 metres, and in this case the motivation is the political determination to increase food production regardless of cost.

b) In high rainfall areas there still remains after terracing the problem of how to safely dispose of surface run-off. Indeed the construction of terraces often makes this problem more difficult.

c) Unless the soil is unusually deep and uniform or unless the topsoil is carefully replaced, the process of terracing is likely to result in lower fertility.

Slope modification need not be a complete change to bench terraces. A partial terracing effect has been deliberately encouraged in many countries by a combination of moving soil downhill by cultivation, and holding soil by contour bunds or banks.

5.2 Length of slope

Again, the effect of length of slope is well documented. In a similar relation

$$\text{Erosion} = c\,L^{d}$$

where L is the length of slope and c and d are constants.

If erosion is expressed in loss per unit area the value of the exponent d will be less than 1.0, and typically about 0.5, showing that erosion is less sensitive to length of slope than it is to the degree of slope.

In the Universal Soil Loss Equation the effects of length and steepness are combined into a single factor. Although the relationships of S and L are empirical and derived from US data, here is one case where the relationship appears to be equally valid in other situations. In general the effect of these two topographic factors is well understood.

The effective length of slope can be easily modified by cross-slope mechanical protection methods such as graded channel terraces, as well as bench terracing. These practices will be discussed under the effects of management in Section 6.

5.3 Effect of adjacent land

Surface run-off may be affected by surrounding land. Higher land may discharge surface run-off onto a field and so make the problem of erosion control much more difficult. Similarly most systems of mechanical erosion control on arable land depend upon gathering the run-off and disposing of it in an orderly manner, and this may be difficult if the lower land has been so developed that there are no suitable drainage ways. This may mean that the technical solution to erosion cannot be applied to small pieces of land or to individual farms, but must be applied on a larger scale. An extreme example of this problem occurs in central India where intensive cultivation of small fields, and progressive subdivision, have led to a patchwork of arable land covering the whole land surface. Any attempts at logical soil and water control are frustrated because there are no adequate drainage channels and no available land where they could be constructed.

However this is essentially a problem of socio-economics, legislation and extension. Our understanding of the effects of topography is adequate, and the question is whether we have the right techniques for effecting desirable changes. Present practices, and whether they meet the requirement, are considered in the next section.

6. EFFECTS OF MANAGEMENT

6.1 Land selection

The first principle of sensible soil conservation and management is appropriate land use, which means matching the use of land to what the physical and ecological conditions make possible. We can ease the constraints caused by waterlogging if we drain land, and we can reduce the risk of erosion by applying soil conservation methods, but there are limits to the modifications which we can make. If land is inherently unsuitable for arable use, it is better to use it for some other purpose rather than to try to change the limitations.

The difficulty of applying this principle in practice is that it may conflict with regional or national wishes. It may be ecologically right for a country to put all its land under, say, rubber trees and import all its food, but self-sufficiency and import substitution are the battle-cries of today's politicians and economists.

Fortunately we do have some useful tools with which to carry out sensible land use planning if politics permit. Where conditions are roughly comparable to those in the USA, i.e. lots of good land and a good appreciation that it is an asset to be used but not over-exploited, then the Land Capability Classification first developed by the USDA SCS is the starting point. Subsequent modifications in many countries have shown that with some adaptation to local requirements it is surprisingly versatile. However, it was derived for land with moderate slopes and a temperate climate, and is unsuitable for the steep slopes and harsh climates of the humid tropics and for the semi-arid regions of the subtropics.

We do have the outline of a classification system for the steep lands of the humid tropics, developed mainly by Sheng from experience in Taiwan, Malaysia and the Caribbean (Sheng, 1971), but this system has not been adequately published or tested on a large scale.

In the case of the semi-arid regions the distinction between land use and land management becomes blurred. With low rainfall the land use must be dominantly grazing, but it would be helpful if we had a system for assessing the capability of grazing land in the same way that we can differentiate between different classes of arable land, and then go on to specify the management techniques appropriate for each class. Perhaps there is a need here for another coordinated worldwide research study of the basic principles.

The question of land classification and recommended use cannot be separated from the pressure on the land. These pressures may be the result of social habit rather than real requirement; for example, in some countries in Africa the population density has in the past been so low that there was always enough land for everyone. This has led to the cultural ethic that everybody has the right to own his own land, a proposition which is becoming untenable as the population increases. Another form of pressure on the land comes with hereditary fragmentation of landholdings. This must inevitably lead to more people on smaller holdings and eventually the point comes where the pressure is so heavy that rational long-term land use is not possible.

An interesting example of the interaction between technical opinion and pragmatic action comes in a recent issue of the Indian Digest of Soil and Water Conservation. The journal invites comment from all interested parties, and particularly the professional conservationists for whom the journal is intended, on whether the present limitation of cultivation should be relaxed. The points for and against listed in the questionnaire (attached as Appendix A) show the difficulty of reconciling the conflicting requirements.

6.2 Land management

It is convenient to divide conservation control into mechanical protection measures and agronomic or biological measures. Those works which involve a large amount of earth-moving clearly fall into the class of mechanical protection, but the dividing line is not precise - for example, contour ploughing might well be included in either group. Neither is it straightforward to separate land management, i.e. the manipulation of the soil and land, from crop management. Again, in which group does contour ploughing fit? Since this paper is concerned mainly with the protection of arable lands it may be appropriate to review current practices in groups according to the kind of arable farming.

6.2.1 Gentle slopes

Up to about 1° slopes it is usually possible to control erosion by simple methods such as strip cropping and contour ploughing. At 1° or 2° it becomes necessary to introduce some system of regular drainage, and between 2° and 7° the classical mechanical control system developed in North America comes into its own. There are three basic components of the system as shown in Figure 2. At the top is the stormwater diversion drain to intercept the storm run-off which would otherwise flow down from the higher ground on to the arable land which it protects. It is an open drain, usually in bare earth, and on a gentle gradient. It is the first line of defence and all the structures lower down will be designed on the assumption that it will effectively control all the run-off from outside the arable land. If it fails to do this, and is breached the water released will almost certainly breach the lower works. It may be called a storm drain, stormwater channel, diversion terrace, or diversion ditch.

The run-off from the arable land is caught in similar but smaller drains spaced at regular intervals down the slope. The channel is usually kept free from vegetation and the excavated soil forms a bank on the downhill side. They are usually on a gentle gradient to lead the run-off safely off the arable land. In different countries they may be called channel terraces, or graded terraces, or contour ridges.

The stormwater drains and the channel terraces can discharge into a natural drainage channel if there is a suitable one in a convenient position. When this is not possible, an artificial channel must be provided. This will also be a shallow open drain, but with a good grass cover, and running straight down the slope. It needs careful design to avoid the flow causing erosion. The usual names are grass waterway or meadow strip.

This system has proved to be effective in many countries, and over a wide range of rainfall. It is particularly suitable where low pressure on the land makes it possible to restrict arable land to slopes less than about 7° or 8° (12-15%). The design procedures for these works are well developed and documented (Cormack, 1951; Schwab *et al.*, 1966, Hudson, 1976).

6.2.2 Steeper slopes

At slopes above 7° (12%) it becomes increasingly difficult to construct channel terraces and the proportion of land taken out of cultivation increases. At this point permanent arable land is best achieved by bench terracing. Again the technique is well developed (Sheng, 1971). The variables are the width and height of the terraces, determined by the soil depth and the crop requirements, and the slope of the riser, determined by the stability of the soil. Grass-backed terraces are increasingly popular in the United States, and a planted sod-forming grass is used to stabilize the back slope at a steeper angle than would otherwise be possible.

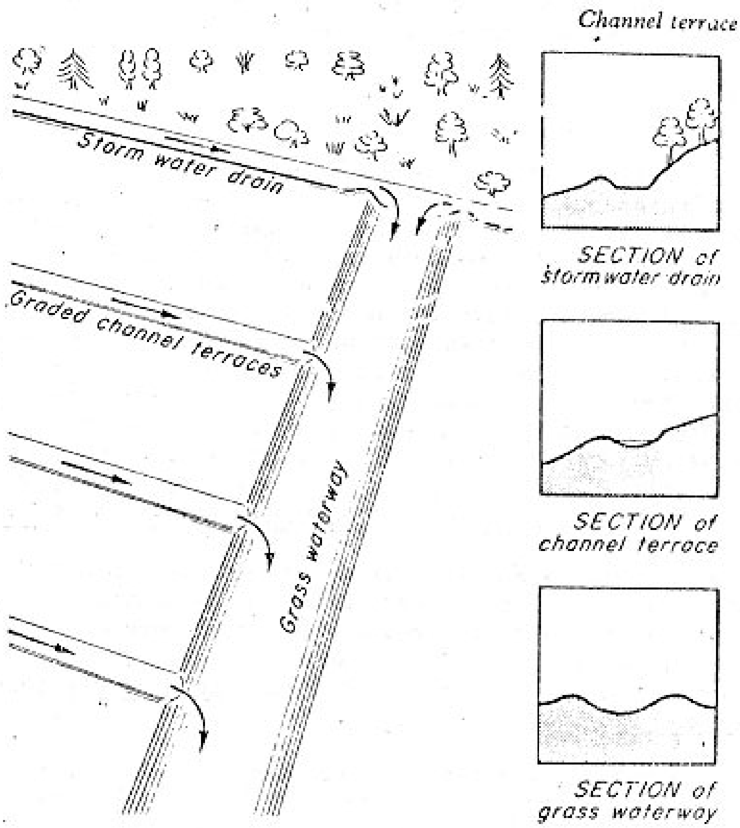

Fig. 2 The basic components of mechanical protection

a) the stormwater drain which diverts storm run-off originating off the arable land.

b) the graded channel terraces leading away the run-off from the arable land.

c) the grass waterway into which both stormwater drain and channel terrace discharge.

As the land slope increases it requires an increasing amount of earthmoving to construct terraces which are wide enough to be treated as arable land. The upper limit of slope suitable for bench terraces is about 15° (36%). On steeper slopes smaller terraces are best, called step terraces or orchard terraces, and are suitable for fruit and other tree crops. Ground cover is required to protect the ground between the trees from splash and to give some protection from surface run-off if it occurs.

Above 25° (42%) and up to 33° (65%), discontinuous or intermittent terracing should be used, where small platforms are levelled for individual trees, but most of the land is either left undisturbed or, better still, planted to a close-growing cover crop. Above 33° any cultivation is both difficult and undesirable. A summary of this approach to conservation practices on steep slopes is shown in Figure 3.

6.3 Crop management

It is in the area of crop management that the most effective control of erosion on arable land can be achieved. The significance of splash erosion as the starting point of the erosion process was only appreciated after the work of Ellison in the 1940s, but the fact that erosion can be largely controlled by the provision of a protecting cover at the soil surface had been demonstrated in the 1890s by Wollny in Germany on small plots, and the same principle was discovered anew by Miller in the 1930s in field experiments. In the pioneer conservation work in the USA between 1930 and 1950 the key factors were mechanical control based on the channel terrace, and the introduction of close-growing crops and crop-residues, and the use of sod-forming crops in rotations.

Since then, the effect of crop management in what we might call North-American style arable farming has been thoroughly studied and every aspect evaluated. In the Universal Soil Loss Equation the C factor representing cropping practices can be assessed with much greated precision than any of the other factors in the equation. Wherever the same style of arable farming is practised, i.e. large-scale, mechanized and concentrating on cereal crops in rotation with forage crops, the results can be applied with only slight local modifications.

However in many developing countries this is not the pattern of arable farming. It is more likely to be small-scale and intensive, multi-cropping rather than single crops, with little or no mechanization, and quite likely a completely different philosophy on weed control. In this situation our knowledge is inadequate and there is a need for a major research effort.

6.4 Research needs for management

In the field of mechanical protection and land management we have a wide choice of techniques. Most are well used and design methods are available. There will always be some place for localized applied testing to see which technique or which design is best, but on the whole the available practices are adequate.

In crop management for what I have termed the North-American pattern of arable farming the position is similar. The principles are well known, a great deal of detailed work has been done, and all that is required is limited local testing and development.

However, in the case of the small-scale intensive arable farming so widespread in the developing countries the position is very different. Something more is required than a modification of the practices developed in a different situation. Nor is it sufficient to think of research on erosion control in isolation. What is required is a study of the whole system of arable farming in developing countries.

At two of the International Institutes such a programme is under way: at IITA for the humid tropics, and ICRISAT for the semi-arid tropics. But these two programmes together only muster a handful of scientists. The scale of the problem and the urgency of it, suggest that there should be a hundred times more.

LAND CLASS	MAXIMUM SLOPE DEGREES (Note 1)	MINIMUM SOIL DEPTH (mm) (Note 2)	CONSERVATION TREATMENT	MAXIMUM INTENSITY OF LAND-USE
1	7		0-2° Contour cultivation	Any
			2-7° Channel Terraces	Any
2	15	1000	Bench Terraces	Any
3	20	500	Step Terraces	Close-cover crops and semi-perennials
4	25	500	Step terraces or hillside ditches	Tree crops with ground cover
5	33	250	Orchard terraces or platforms	Tree crops with ground cover (no cultivation)
6	More than 33	-	None	Forest only.

Notes: 1. Equivalent slopes are 12, 27, 36, 42, 65 per cent.
2. Minimim soil depths are required when terraces are to be cut into the hillside.

Fig. 3 Criteria for land capability classes in the humid tropics

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Paper No. 14 DEVELOPMENT OF SOIL AND WATER SERVICES IN DEVELOPING COUNTRIES - SPECIFIC REQUIREMENTS AND POSSIBILITIES FOR ASSISTANCE

by

N. Gil

1. THE PROBLEM

1.1 Existing Services

In most developing countries certain components of soil and water services exist; sometimes they are found as different departments in one ministry but very often two or more ministries may be involved. The services provided by these many units are usually not coordinated and cooperation between them, in most cases, is non existent.

1.2 Soils Surveys

Lately soil and land use surveys have been carried out in many countries or are part of their development plan to be implemented. Assisted by internal institutions or bilateral aid, such surveys are carried out on a reconnaissance or semi-detailed scale. Soil laboratories with sophisticated modern equipment are often part of such projects which also include the training of local scientists. Generally, a high scientific level is applied and followed up by more or less intensive research on specific problems found during these surveys.

Special maps are prepared as a result of the surveys, mostly on a scale of 1:25 000 or 1:50 000. Furthermore the soil survey unit is a special service which may sometimes be called for assistance on specific problems but is not involved in the daily requirements of land use and farm management of individual farmers or small village communities. Sometimes the results of these surveys may also be available and used on this practical level of direct application on the land. Very often however there will be little or no contact between the soil scientists and the field extension worker, who generally has a much lower level of education and has no training in this specific subject.

With regard to farm management which necessarily includes good soil management, it will be often the soil scientist who lacks knowledge on this subject and very often is not even interested in it.

1.3 Water Services

In most countries where irrigation is required, some sort of water services exist. They may have very different organizational structures and sometimes belong to ministries which are not directly connected with agricultural production. Farmers irrigation associations, with or without government supervision, may often be responsible for distribution of irrigation water. With a few exceptions some water laws and regulations exist. In most cases they are based on traditional customs and are not adjusted to the requirements of the changed conditions of today. Even improved laws, few as they are, may be difficult to enforce to bring about the necessary improvements to meet the rising demand for irrigation water, its proper distribution and its supervised use.

Practically without exception there is wasteful use of the limited resources of irrigation water. Even, in new projects lack of consideration for the requirements of effective irrigation can be observed. New and large irrigation schemes have often caused severe damage to the land through alkalinity, rising watertables and creation of man-made swamps.

Some of the major characteristics of most water distribution systems are the losses in canals, the lack of proper and continuous maintenance and the distribution according to area irrigated and according to quantities supplied. Payment is also according to area unit irrigated and only in rare cases exact water measuring devices are installed and payment collected per m^3 used. Consequently, wasteful irrigation can be observed in countries or locations where the supply of additional water for irrigation is a major problem.

Furthermore, except in areas irrigated from large rivers with fairly constant flow, a gradual decrease in available water is evident, caused by deterioration of watersheds through man's activities. Seldom, however, do water services have any part in or concern with this phenomenon whose very real implications touch the water services themselves. Flash floods, sedimentation in reservoirs, diminishing flow during dry seasons and falling groundwater tables are the results of destructive activities in watersheds, but water services are generally not involved in the activities to restore the water balance in a given area or a whole country.

1.4 The Missing Link

There are services which deal with some aspects of soil conservation on arable land; other services or ministries, such as forest departments, may be concerned with erosion control on uncultivated areas. Special units may be involved in irrigation and/or drainage activities. Separate farm management units may be active in the framework of extension services, mostly on a limited scale. But no special service for comprehensive soil and water conservation exists in any developing country. Such a service could be given different names, it could be part of a ministry, or an independent ministry, it could be a coordinating body between department and ministries. To be effective it must have authority on all aspects of land and water use and the conservation of the available natural resources. Without such a comprehensive and integrated approach and a responsible authority for implementation, no basic changes in the present situation of unrelated and non-existing activities to conserve and improve the rapidly deteriorating natural resources for agricultural production can be expected.

The establishment of such a multidisciplinary agency in countries with a vertical administrative set up with very little or no horizontal coordination is certainly a major and difficult undertaking.

2. SOLUTIONS

2.1 General

The multidisciplinary character of soil and water conservation and the development of adequate soil and water services in developing countries is a difficult problem. The urgency to establish such services in most countries is evident. Rapidly increasing population and diminishing resources of land and water on an accelerated scale are a clear indication of the necessity to act without further delay to prevent additional losses and to repair damage already done. The existing administrative and professional units in governments, each dealing with one or two specific subjects, are indeed fully aware of the dangers and make efforts to solve the difficulties and problems in their own limited fields of activities. Requests for assistance are increasing and large amounts of money are spent on projects dealing with these subjects. However the results are rather discouraging. Some possible ways to establish such essential services will be discussed and evaluated.

2.2 Suggestions

i. To train technicians of the different existing services, dealing with some of the components, in a comprehensive and integrated approach to the multidisciplinary character and requirements of land and water services. To return these technicians after training to their original positions in their diverse units.

This system of training sessions and workshops on specific problems is an highly estimated and often used method by many international and bilateral aid organizations. It is based on the general principle that education is the first step towards progress. However, by closer examination of the possible positive results of such activities in this specific and unique field it soon becomes evident that practically nothing can be gained by such training courses, except the general and laudable educational progress of individual technicians. In most cases junior technicians will take part in such workshops. Even if senior officers are delegated, they will be in no position to bring about changes in the administrative set-up. Policies are made on a much higher level and in most cases not by professionals in a certain discipline but by administrative officers and top government bodies.

No support should be given to requests for the above system nor should FAO use its influence and money for such projects.

ii. To establish a special soil conservation service which may fill the needs for erosion control and soil and water management not covered by already existing services. This new service may also be given the task of technical assistance to other departments.

This approach is not likely to give better results than (i) above. It may give some valuable assistance in the field and improve certain aspects of land and water management, but it would be in no position to bring about the necessary basic changes in the professional and administrative organization within a government. Furthermore, its advisory function would be of little value even if such advice is sought, which is rather doubtful. Advice may be accepted or rejected. In most cases, it will be rejected because it may create difficulties which were not encountered before. Soil and water conservation and the services required from such a related organization cannot depend on the goodwill of others.

iii. To establish a strong soil and water service, which will deal directly and from the grass roots to the policy making level with all the many subjects to be covered by a multidisciplinary agency. This would mean that activities, formerly carried out by other agencies, be transferred together with their professional staff, to this new and strong organization.

This system would have a good chance of success. It is however doubtful if governments would take such extreme steps in changing their existing organizations which have been evolved over a long period of time. Should a government however take such steps and apply for assistance, it should certainly be granted.

The role of governments and of FAO in such projects will be discussed under 3 and 4 below.

iv. To follow up the systems under (ii) and (iii), it is possible to find another way to build up gradually a strong and integrated soil and water service.

As a start, a small soil conservation unit as explained under (ii) could be established with a pre-planned sequence and timetable to absorb gradually other disciplines in a soil and water service with different divisions under one overall management. Such a service should include, after a number of years, many departments, for example: land use, soil and farm management, erosion control, soil conservation on agricultural lands, land consolidation, range management, irrigation and drainage, flood control, surface water storage, groundwater resources, etc. It could also contain one special section for comprehensive watershed management. Such a unit could even be the first section in this new service, being involved in practically all disciplines mentioned above.

v. This watershed management unit could be an important stepping stone in the establishment of soil and water services. It could and should start with rather small projects, covering one or two subwatersheds, prepare the plans and be responsible for their implementation.

During this period it is likely that a number of hidden an unexpected factors of a technical and administrative nature will arise and ways to overcome such difficulties could be explored. Fortuitously this may be a good start because of the multidisciplinary character of its activities and its staff. Furthermore it would be an easy way to demonstrate the comprehensive and integrated approach, to observe its advantages and disadvantages, and be the foundation on which government decisions for the establishment of unified soil and water services could be based.

Request for assistance for such projects should certainly be granted.

3. THE ROLE OF GOVERNMENTS IN ESTABLISHING SOIL AND WATER SERVICE

Land and water are the basic natural resources. The rural population should be added as the third resource, as they are the beneficiaries and the driving force for the effective and sustained use of the resources.

Governments have asked and received assistance for large projects, dealing in most cases with single subjects. This may help to solve individual problems. Such projects, even if successfully concluded, have all the short-comings of a patchwork approach. The results are available, the local staff has been trained and sometimes even continues work on the project subjects, but the impact on the overall improvements in land and water management remains extremely limited. Also very often there is no continuity after the termination of projects. The trained staff is absorbed into other services which have no relation to the project subjects.

If a government seriously wishes to improve its land and water resources, a very radical change in policies will have to take place regarding its own contributions and its dependency on foreign advisers. In the field of land and water services no large scale projects with heavy inputs for equipment, laboratories and services of expatriate technicians should be expected. No monuments will be created. It is mostly the government itself which has to make decisions and take the necessary steps for implementation within the framework of its own policies.

Assistance will certainly be needed, but much more of the locally available resources of technicians, administrators and equipment should be involved to find the solutions and to carry them out, whatever the findings may be. Land and water services are so closely related to the day to day life of the population and to the national economy, that without decisions and actions from the highest level of government down to the field technician at the village level, no practical results can be expected.

4.. ASSISTANCE TO DEVELOPING COUNTRIES

One of the important phases of assistance to developing countries may be the explanation of the policies laid down under 3 above. If a clear and positive understanding can be reached on this point, it will be easier to define the limits and the form of assistance that can be asked for by – and be given to – governments for the establishment of efficient soil and water services.

This basic explanatory drive could be carried out by the Regional Offices or by senior Headquarters staff and no special expenditure would be required.

The next step would be the preparation of a project document, jointly agreed by government and FAO. This could best be done by a one-man mission of a highly experienced staff member or consultant to the country requesting assistance. Such a mission would require between 1–2 months of investigations, negotiations, discussions and preparation of the document which should include all details of work, schedules, staffing, equipment, offices, supporting services, budgets etc. Above all, it must include a clear statement of intention by the government, its decisions on legislation and regulations – if required – and its committment to follow-up after termination of the project. It will also contain the services of advisers.

Not more than one permanent adviser should be allocated for the duration of the project. All other expert services should be restricted to short-term consultancies. The main burden should be borne by local technicians. Projects of this kind should have a duration of 1–2 years not counting the preparatory mission. The assistance in monetary terms would be small and not over $ 250 000.

Within the structure presented in this paper, viable projects at low cost could be carried out for the development of soil and water services in developing countries. It can also be hoped that, due to the close involvement of governments and their agencies there might be a successful follow-up after the termination of such projects.

Paper No. 15

TRAINING, EXTENSION AND IMPLEMENTATION OF SOIL CONSERVATION PROGRAMMES IN DEVELOPING COUNTRIES

by

O.F. Jones

A soil conservation action programme must provide the education, technical expertise, and necessary incentives so that the land users will use the soil within the limits of its physical characteristics and protect it from unalterable limitations of climate and topography. It is essential that we have a clear understanding of what is involved in a soil conservation programme to make it an effective one.

Assisting land users to do this is a very big task. It requires expertise in many disciplines. The fact, that soil conservation is multidisciplinary in nature, makes it difficult to train a staff to a competent level of proficiency. The problem of training is not necessarily made difficult because a number of different disciplines are needed, but mostly because almost all of the disciplines must have some appreciation and understanding of other disciplines involved. Ideally, the soil conservation planner should have a working knowledge of all of the disciplines which are needed. Without that kind of an expert, it is necessary to use a team approach to planning. Experts in soils, agronomy, and engineering are usually needed to adequately plan a project area. Experts in many other fields such as economics, irrigation, biology, hydrology, geology, and other disciplines may be useful and needed in many cases for the planning of a soil conservation project and application of practices.

A look at the types of jobs which need to be done to plan and apply a conservation programme on a project area, will give an even better insight as to the kinds and amount of training needed by the technical staff.

1. PLANNING PROCEDURE

1.1 Information on the area needs to be gathered about soils, topography, and climate on all project areas, regardless of size. On the larger areas data should be gathered on crops, population, social structure, infrastructure, and other factors which may affect planning as well. The planner is probably well aware of the effect of those factors on smaller project areas. This involves gathering data in the form of maps, publications, and reports, as well as data which may need to be gathered in the field.

1.2 Soil degradation problems should be identified. This requires an ability to recognize at all stages, the many processes of soil degradation such as wind and water erosion, waterlogging, salinization or alkalization, and pollution.

1.3 A determination of the land treatment needs should be made. This requires an understanding of the kinds of practices or treatment measures which are needed to control or correct the degradation process which is taking place. A thorough knowledge is necessary of about 100 practices as to when, where and how they apply. All alternative solutions need to be considered as well. Rough cost estimates may be needed for making a practical evaluation of alternatives.

1.4 All alternative solutions should be presented to the decision maker. This involves having a clear understanding of what each practice will accomplish, as well as the benefits which can be expected as compared to the cost of installation for all the alternatives. It is also essential to anticipate and analyse any installation difficulties and work out a realistic timetable for application.

1.5 Final plan preparation involves the assembly of all pertinent information needed to carry out the plan in an orderly manner.

2. PLAN APPLICATION

Application of the plan includes the design, stake out, construction, checking of adequacy, monitoring effectiveness, and maintenance.

2.1 Most people associate design with engineering constructions such as dams, drainage systems and water control structures of all kinds. Other measures may also need to be designed and even though they may not require so much in the way of hydrological considerations, they do, in most cases, require agronomic consideration in relation to soil and climate. All structures should have standards for application or specifications which are adapted to the local conditions.

2.2 Most practices, which involve earth moving, require staking to determine areas from which material can be excavated and where depositions should be made, as well as to locate appurtenances which may be a part of a structure. Staking out or layout and design is also needed for most other measures to determine quantities of materials needed and area to be treated in order to make cost estimates and for record-keeping purposes. For instance, with any conservation practice which involves seeding, sodding, or tree planting, it is essential to know the area involved to determine the quantity of materials needed, such as seed and other soil amendments.

2.3 Constructions particularly those which involve earth moving or masonry work, require knowledge of capability and limitations of the equipment, ability to analyse quality of construction materials and workmanship, ability to compute quantities of materials, and a thorough knowledge of construction techniques, equipment operation, and safety hazards involved.

2.4 The check for adequacy of construction requires a thorough knowledge of the specifications for the particular practice, and the ability to recognize visually weaknesses of construction, and to design corrective measures.

2.5 Monitoring the effectiveness of conservation measures after they are installed, requires an understanding of how they are designed to function and an ability to analyse whether or not they are performing that function.

2.6 Maintenance after installation again requires an understanding of the specifications for the practice involved, and it may require ability to redesign sections of a structure or to recognize the need for complete redesign in the case of design failure.

All the jobs in a soil conservation programme require special skills of one kind or another, so the challenge is how to impart these necessary skills to staff in the most efficient manner.

3. TRAINING REQUIREMENTS

The effective implementation of a soil and water conservation programme can probably be most efficiently achieved by a combination of people - some who have a broad overall understanding of the interrelationships between disciplines and the general requirements for land treatment, and the more specialized type personnel who are capable of making detailed studies, surveys, and designs for specific practices. It is recognized that the overall job of planning and applying a conservation programme could usually be accomplished by competent college trained people who are classified as professionals. To do the entire job with only professionals, however, would not be efficient from a training requirement standpoint, and most developing countries do not have an abundance of college trained people. Fortunately, many of the jobs which need to be done can be accomplished by staff who are not college trained but only trained in how to perform specific tasks. This kind of non-professional personnel can be particularly useful in the gathering of information for design, such as topographic surveys and cross-sections. The non-professional can also become highly proficient in the layout of simple mechanical type measures such as contour lines, terraces, and waterways. The secondary school leaver with sound basic education and an interest in agriculture can usually be trained in these types of skills, primarily through on-the-job training which does not require high investment in training facilities and special teaching staff. It also has the advantage of keeping all of the training job oriented and practical.

The alternative to on-the-job training for non-professional staff is a formalized training programme. This can be set up as a special curriculum at established schools of agriculture or in a training institution established specifically for training soil conservation staff. There are advantages and disadvantages to either approach.

The advantage of using established training institutions is chiefly that, upon completion of the course of study, appropriate certificates or diplomas are usually awarded which represent the level of academic achievement. These are usually recognized throughout the government for establishing grade level and salary of employees. The disadvantage is that most institutions lack the facilities to provide sufficient in-the-field practical training; and adequately trained teaching staff, with practical field experience, may not be available.

The establishment of a training institution within the framework of the organization, which has the responsibility for carrying out the soil conservation programme within a country, has the advantage that training would be more closely tied to actual field projects and instructors would probably be practising professionals with a better insight into the jobs needing to be done. The facilities established could be alternately used for staff refresher courses and in-service training programmes. It has the disadvantage of not being able to offer academic achievement certificates and diplomas unless special arrangements are made with academic institutions.

The problems of recruiting and training staff for soil conservation in developing countries are many. Some of the more serious problems envisaged include:

1. the lack of interest in agriculture or agricultural problems by students who have received formal schooling;

2. reluctance on the part of college trained professionals to become involved in the field work to the extent necessary to transfer textbook knowledge to practical field application;

3. the quality of primary and secondary education many times requires that additional basic education in mathematics and elementary sciences be given along with on-the-job training before proficiency can be achieved;

4. the lack of emphasis on agricultural development as compared to military, industrial, and commercial expansion by many governments has caused positions in agriculture to be regarded as less prestigious than similar positions in other ministries.

The extreme difficulty which may be encountered in overcoming the above mentioned problems and others does not minimise the importance of overcoming them, if sound technical assistance programmes in soil conservation and agriculture in general are to be achieved. Some of the solutions which seem to be essential to achieve the objectives include:

a. upgrading of the quality of primary and secondary education;

b. a greater recognition needs to be given to the importance of agriculture, agricultural development, and conservation programmes by many governments.

c. more emphasis needs to be placed on practical application of knowledge gained in higher degree training;

d. improvement in the amenities and terms of service offered agricultural experts by governments needs to be achieved.

4. EXTENSION AND IMPLEMENTATION OF SOIL CONSERVATION PROGRAMMES IN DEVELOPING COUNTRIES

This is discussed as a single subject because most developing countries use extension techniques and extension institutions as vehicles to implement soil conservation programmes. The fact remains, however, that countries which have apparently been most successful in implementing strong action programmes in soil and water conservation, such as the United States, Australia, and New Zealand, have all resorted to special institutions to accomplish the task.

At first glance, there would appear to be many advantages to using the extension institutions which already exist in most developing countries for the implementation of soil conservation programmes. Most political leaders view it as expeditious because it eliminates the cost of establishing a separate institution. This reasoning may be valid in cases where budgets are limited and the problems of soil conservation are simple. Extension organizations are usually understaffed in most developing countries and the addition of further responsibilities may only further dilute their overall delivery capability. As is already well known, extension workers in most developing countries are handicapped in the performances of their regular duties by many factors, such as lack of facilities, equipment, training, transportation, backstop support, and materials. The well-trained extension worker can be very effective in instances where soil conservation can be achieved by the use of good crop husbandry practices only. It is difficult to visualize the situation where an extension worker could effectively handle problems which are complex without strong support from a proficient well-trained technical staff. Many times half-way measures, when applied, result in more severe soil degradation than if no treatment were applied at all.

All of the techniques used in extension work need to be used in bringing about the adoption of soil conservation programmes by land users. It is probably in this area that the ordinary extension worker can be most useful in a soil and water conservation programme whether or not a special institution is created for implementation. The training and education needed to effectively implement the programme goes far beyond the training of technical staff discussed earlier. It must be carried to the land user so that he has a clear understanding and appreciation of the need, purpose, and results to be achieved.

Some countries have instituted special training courses for extension workers on soil conservation. This would appear to be a feasible solution to the need for technically trained personnel and in some cases it may be, but in some cases, results have been disappointing. The chief problem appears to be organizational in that when the employee returns after training to work within the regular extension organization, he finds himself outside of the mainstream of the organization for promotion and advancement, his supervisor may have little understanding or appreciation for his newly acquired skills, and he may be given assignments unrelated to the tasks for which he was trained. This leads to extreme employee frustration and resultant lack of accomplishment. These problems should be relatively easy to solve by creation of a special task force or unit within the extension service for soil conservation. The highly specialized skills required for planning and application of special practices for soil conservation precludes, in my opinion, the possibility of development within the regular extension organization of an effective soil conservation programme, except in rare cases where special practices may not be required.

The cost of installing many of the practices essential in a soil conservation programme inhibits implementation of the programme unless incentives are provided. Governments generally have recognized the need to assist land users and land owners by paying a part or all of the costs of installation of special practices in addition to providing technical assistance without charge. The land tenure systems which vary from country to country make it impractical to attempt to conclude that any particular system of incentives is superior to another. However, one principle does seem to prevail, depending upon how much control and long term interest the land user has in the land, and that is, that if the land user has some investment in the practice, he has more understanding and appreciation for the practice and will have more interest in maintaining it. The United States government has had the policy of paying from 50 to 75% of the cost of installation of special conservation practices on private lands. Similar cost sharing arrangements have been carried out in other countries.

In Nigeria, we had a project where costs of constructing hand built terraces were shared between the farmers and the government. The farmers contributed one day of labour each week as his share, while he was paid wages for the other five days. Acceptance of this project was better than those in which the government carried out the whole job without involving the farmers.

Another very serious deterrent to establishment of effective country-wide soil conservation programmes in most countries of the world, is the lack of flexibility in land use. The extension organization is usually based within a ministry of agriculture or its equivalent, and as such, serves only what is called agricultural land used primarily as cropland. Soil degradation occurs not only on agricultural land but also on lands used for other purposes such as grazing land and forests. The same kinds of expertise and practices are needed to solve the soil degradation problems on those lands as are needed on agricultural lands. Without the creation of a soil conservation organization whose services would be available to all of the ministries with jurisdiction over land, soil conservation trained and oriented staff would be essential in each of the ministries before effective soil conservation programmes could be implemented to cover all lands. Such duplication of activity may prove to be a wasteful use of scarce trained manpower resources.

5. CONCLUSIONS

1. To be effective a soil conservation staff must be based within an organizational structure capable of accommodating its needs.

2. Technically trained staff is needed to effectively implement a soil and water conservation programme.

3. Incentives for installation of special practices need to be provided.

4. More land use flexibility could provide practical alternatives to installation of costly special practices in many cases, thus reducing costs substantially.

Paper No. 16

ENVIRONMENTAL PERSPECTIVES OF LAND USE POLICY IN RELATION TO SOIL AND WATER CONSERVATION

by

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1. SUMMARY

The environment is defined as that whole outer physical and biological system in which man and other organisms live and interact in accordance with their intrinsic characteristics and needs. The wise management of that environment depends upon an understanding of its components. It demands positive and realistic planning that balances human needs against the potential the environment has for meeting these needs. Good management avoids pollution, erosion and the wastage of resources by irreversible damage.

Technological innovation in agriculture has been restrained very little to-date by environmental considerations. A farmer uses fertilizers and pesticides to the extent that his knowledge and judgement suggest that it is profitable for him to do so. He does not consider the environmental problems that fertilizers and pesticides might create by polluting and eutrophying downstream rivers and lakes etc.

With the forementioned considerations as a background the paper presents relevant informative accounts on - the nature and goals of land use policy; role of land use policy; guidelines for land use policy and action foci of land use policy subject areas.

2. INTRODUCTION

The environment is defined as that whole outer physical and biological system in which man and other organisms live and interact in accordance with their intrinsic characteristics and needs. The wise management of that environment depends upon an understanding of its components: of its rocks, minerals and waters, of its soils and their present and potential vegetation, of its animal life and potential for livestock husbandry, and of its climate. It demands positive and realistic planning that balances human needs against the potential the environment has for meeting them. Too many people think only of pollution when they consider environmental problems. Good management avoids pollution, erosion, and the wastage of resources by irreversible damage. To prevent such types of environmental degradation is even more challenging and certainly more efficient than to redress them after they had occurred.

Both the creation and the recognition of environmental problems depend closely on the way society is organized, and on its values and objectives. Changes in the relationship between man and his physical environment depend to a large degree on changes in the organization and aims of society. If man is to escape from a situation in which much energy and resources are devoted to correcting past mistakes, his aim must be to build a society which is intrinsically compatible with its environment.

The fundamental needs of a human being are hard to define. Our perception of them varies according to our culture, time and technological progress. But some may be considered "basic" because unless they are sufficiently satisfied, dignified and active human life is impossible. They are food, shelter, health, clothing, education and creative productive work, and they are felt by every human being irrespective of culture, race or sex. Closely linked with them there is another group of "social" or "cultural" goals such as entertainment, participation in social affairs, travel, choice of employment and the like. It is hard to draw the line between human needs and desires. Once basic human needs are satisfied - and this in itself will be difficult to achieve throughout the world - people still have wants which relate to individual standards but also strongly reflect cultural influences. Aspirations and expectations mount as societies develop and economic growth proceeds: they are never fully attained. It is a feature of man that he is always searching for new goals - of knowledge, successful rural or urban economic enterprises, art, social choice, or physical quality of life. It is within this psychologic context that the lives of the farming commuritites are oriented towards attaining higher levels of accomplishment in promoting their environmental qualities from the aesthetic, cultural and socio-economic points of view.

This paper will review the environmental problems that confront developing countries as a background for delineating the problem, the nature and goals of land use policy, the role of land use policy, the guidelines for land use policy and the action foci of land use policy subject areas.

3. THE PROBLEM

Technological innovation in agriculture has been restrained very little to date by environmental considerations. A farmer uses fertilizer to the extent that his knowledge and judgment suggest that it is profitable for him to do so. He does not consider the environmental problems that fertilizer use might create, for example, eutrophication of lakes as a result of runoff. He applies chemicals to control insects, pests, and diseases to the extent that he thinks it will be profitable for him to do so, without considering the possible adverse effects of those chemicals on wildlife or on humans elsewhere. He builds feedlots of sizes and layouts that he thinks will be most profitable, with little if any consideration for manure disposal. And so it goes. Farmers respond to new technologies and to prices of inputs with little or no consideration for the environmental impacts of their actions. Accordingly, pressures upon agricultural resources are increasing. Although over centuries subsistence farmers have acquired an intimate knowledge of local climate, soils, water, plants, and animals and of the maintenance of their productive capacities, the introduction of new agricultural technology and land use systems tends to make some of this knowledge and experience obsolete. It is becoming increasingly difficult for extension and other advisory services to educate farmers in appropriate agricultural practices and in the safe use of new technologies. This is due to the large number of people and production units involved and the increasing rate at which changes are introduced into agriculture.

The problem is particularly acute where new lands are brought under cultivation, where new crops, varieties or breeds of animals are introduced, or where irrigation is used.

Dependence on market conditions and, in some countries, obsolete land tenure systems put additional constraints on the farmer and further limit his ability to manage economically his farm and at the same time maintain the productive capacity of its resources and the protection of the environment. Under these conditions, many farmers, particularly in developing countries, cannot afford to make basic land improvements, and apply soil and water conservation practices.

Accelerated degradation and depletion of basic agricultural resources are resulting from the pressures to which reference was made. Although some forms of natural resources degradation have always existed and can be found at all levels of agricultural practices, increasing problems are found throughout the world which substantially impair agricultural productivity and development. These include:

1. accelerated soil erosion by wind and water, loss of soil fertility, through leaching or depletion of nutrients and decrease in humus content, degradation of soil structure, increased soil salinity, alkalinity and waterlogging under irrigation;

2. loss of useful genetic resources;

3. conversion into poor croplands or depletion of some grasslands by overgrazing;

4. local or regional modifications of climate through removal of forests and tree hedges, causing, inter alia, desertification in sub-arid areas;

5. encroachment from urban and industrial areas and transport facilities on good agricultural lands;

6. discharge of harmful wastes from urban areas and industries on to rural areas.

Intensive agricultural practices can place a heavy burden upon the environment. Many agricultural systems, associating either intensive monoculture or animal husbandry with agro-industries, do not provide for the economical use of by-products and tend to accumulate wastes, the disposal of which becomes the source of major concern. Under developing country conditions these degradation conditions can be expected to arise in the foreseeable future.

4. NATURE AND GOALS OF LAND USE POLICY

From this preamble it is necessary to identify the nature and goals of land use policies and in this respect they are regarded as major lines of public action designed to improve the use of land resources and the conditions of property rights under which people work and live on the land. The goals of a land use policy are governed by what people desire and what the functions of government are conceived to be in bringing about better land use, consistent with the principles of soil and water conservation, and land tenure - the twin aspects of land use policies.

Implicit in any policy are goals toward which that policy is shaped and with which policy results (or expected results) can be appraised.

Since land resource use and environmental quality have become major national concerns in the majority of developing countries and pursuit of these objectives involves consideration of other national concerns, improvements in land resource use and environmental quality must necessarily be approached in conjunction with other national goals. Natural resource and environmental improvements thus join and perhaps compete with economic growth and full employment as major national goals. Conversely, deterioration of natural resources and environment join depression and unemployment as major domestic ills to be avoided or remedied.

Economic growth is defined and measured in terms of an annual percentage increase in the gross national product. Full employment is defined and measured in terms of the proportion of the labour force employed at a particular time. But no well-defined and agreed-upon standard(s) of land resource use and environmental quality exist. Neither are there instruments for measuring and achieving natural resource use and environmental quality comparable to the measures for economic growth and full employment. Without definition and means of measurement, natural resource use and environmental quality, as policy goals, remain obscure and subjective. Also, it is difficult to visualize inherent and strategic interrelationships between natural resource use and environmental quality and other major policy goals, including selection of the goals.

The means for pursuing particular uses of natural resources and environmental qualities are quite different in terms of motivation and consequences for people in different situations. A monopolist can shift added pollution control and resource use regulation costs of his product to consumers. But an individual operating in the competitive business of farming must bear pollution control and natural resource costs himself, at least initially.

5. ROLE OF LAND USE POLICY

In identifying the role of public land use policy it has to be described in terms of three phased background elements. First is a statement of needs for remedial action based on recognized natural resource and environmental problems. Second is a statement of policy purposes that represent a consensus among citizens in terms of what the policy is expected to perform. These purposes should set the goals for improving natural resource use and environmental quality and should be consistent with the norms for delimiting the problems that create the need for the policy. Third, the policy should establish general guidelines and definitive directions for achieving the goals. The guidelines should be supported by a rationale why the guidelines are expected to move natural resource use and environmental quality toward the policy goals.

Thus, policy is regarded as a consensus of public support for the need for action, the goals of the action, and the general definitive directions the action should take in its attempt to achieve the goals. Policy enacted at national and regional levels should be expected to set in motion a continuing process of improving natural resource use and environmental quality in an acceptable and beneficial manner on behalf of the citizenry.

Although development and enactment of land use policy is a first and essential step in proceeding toward improved natural resource use and environmental quality, the policy remains futile unless implemented through (1) land use and environmental planning based on facts and analyses, (2) programmes based on this planning, and (3) programme performance consistent with policy goals. Thus, the policy should recognize and provide for planning, programming, and performance as essential implementation measures.

6. GUIDELINES FOR LAND USE POLICY

One of the crucial elements in formulating land use policy is the establishment of principles to achieve policy goals. Before outlining the action foci of land use policy subject areas, guidelines for developing land use policies at the national and provincial levels have to be determined for delineating a rational course of action on applying sound soil and water conservation programmes. These guidelines are not necessarily presented in the order of their importance. Moreover, they may be stated in other ways through further division or in combination. Nevertheless, the 10 points are relevant to developing land use policies consistent with the nature, role and goals of the land use policy which is to be adopted.

1. <u>Stating land use policy goals</u>

   Land use policy should include a statement of goals that meets two conditions: (i) The goals should provide the ends sought in improving the use of natural resources and environmental quality. These goals should be consistent with the norms used in delimiting the problems which the policy is designed to ameliorate. (ii) The goals should be analysed in terms of other national and state goals, including growth, employment, and income distribution. Preferences most likely would evolve from the process of reconciliation.

2. <u>Providing flexibilities</u>

   Because of variations in resources and geography as well as citizen preferences, land use policy must provide flexibilities without sacrificing achievement of policy goals.

3. <u>Encouraging experimentation and innovation</u>

   Special application of the flexibility guideline would not only permit but encourage experimentation and innovation by provincial and local governments in formulating new approaches to improved land resource use and environmental quality.

4. Providing for planning, research, and evaluation

Imperative in determining land use policy is sound planning founded on facts and analysis provided by applied research. Also, evaluation of on-going programmes is required to make in-process adjustments in programmes and to transfer programmes to other areas. This is especially true with experimental and innovative types of activities.

However, there are real dangers that planning, research and evaluation will be neglected, either because of pressures to get a programme started or more likely because provincial and local governments, already overburdened financially, will not have the necessary funds.

5. Widespread citizen participation

Development of land use policy must necessarily involve citizen participation on a wide scale and at all levels of authority.

6. Preventing fragmentation, duplication, and conflicts

With the current mood for action on land use policy, provincial and national governments may be pressed into fragmentation, duplication, and conflicts of planning and programming government groupings or agencies that could obstruct progress toward achieving land use and environmental improvements.

In the interest of effective land use policy, planning, programming, and performance, the need is to allocate responsibilities to fewer but more effective government groupings or agencies. For example, in the rural areas the establishment of consolidated and multifunctional agricultural cooperative societies and land resource and environmental improvement districts should replace mono- or bifunctional agricultural cooperative societies and soil and water conservation districts.

7. Providing for complementary roles by governments

One of the more important guidelines in developing land use policy is the allocation of functions and responsibilities among local, provincial and national governments. Complementary functions and responsibilities must be developed and accepted by the various levels of government commensurate with the nature and occurrence of problems and the ability and willingness of the citizens to perform.

8. Institutionalizing soil and water conservation and environmental protection incentives

Since development activities related to soil and water conservation and environmental protection will accrue direct benefits to the rural community as a whole, it is the duty of governments to allocate funds to the rural district level where the costs of these development activities are to be spent. Accordingly, governments should institutionalize incentives to service the funding to local and provincial farmers and citizens groups for public land use development activities purposes.

9. Considering all uses and all natural resources

Since products and services derived from natural resources are substitutable within limits and, likewise, natural resources are substitutable within limits, all current and potential uses of natural resources and their environmental effects should come under the purview of land use policy.

The time for single-resource concern is nearing an end. Technological developments allow the use of alternative resources as substitutes for each other, with differential effects on the resources and on the environment.

For example, the land and water resources are substitutable with respect to agricultural production; land can be used for crop and animal production while water can be used for fish culture and production - thus, the products of both resources are substitutable.

10. Modifying property and responsibility concepts

Traditional rights in land evolved in a *laissez faire* manner during the early periods of natural resource exploitation. Now these rights must be modified and qualified to emphasize man's responsibilities in the use of these resources. In other words, property rights can and must be restructured to help eliminate unrestrained exploitation of natural resources and degradation of the natural environment.

7. ACTION FOCI OF LAND USE POLICY SUBJECT AREAS

With the guidelines on land use policy delineation as a background, the action foci of land use policy subject areas may be identified from the following proposed courses of action:

1. To develop agricultural plans and policies to enable farmers and agro-industries to fulfill their responsibilities in maintaining the quality of the human environment

1.10 Agriculture will need to be increasingly recognized as an activity of general public interest:

1.11 for supplying food and other essential products in sufficient quantity and of satisfactory quality

1.12 for ensuring the conservation of a large part of the natural resources and of the environment

1.13 for employment opportunities in order to avoid excessive urban concentrations

1.14 for maintaining and enhancing the quality and attractiveness of rural areas for recreation and as buffer zones between urban areas

1.15 for recycling wastes emanating from sources such as municipal sewage.

1.20 At the planning stage, the adverse environmental impacts of development plans on agriculture, and conversely the harmful environmental effects of agricultural development, should be prevented.

1.30 The local environment will have to be regarded as a functioning ecosystem within which agricultural development takes place and to which it adapts, and not the reverse as traditionally maintained, i.e. the *fait accompli* encroachment of agricultural development upon the prevailing ecosystem. Thus,

1.31 the conventional preoccupation with agricultural outputs must be balanced by a consideration of inputs and their environmental hazard implications.

1.40 The appreciation of the intrinsic qualities and needs of the prevailing ecosystem explains the need for various inputs beyond the capabilities of the individual farmer but requires to maintain successfully an artificial equilibrium which has to conform with the conservation needs of a sustained ecosystem. These include the application of:

1.41 plant breeding programmes and the salvaging of threatened genetic resources

1.42 soil and water conservation practices

1.43 monitoring and control of soil, water, and plant contaminants

1.44 integrated control of insects, weeds and other pests.

1.50 Agricultural and soil institutions should play an increasing role in the assessment of land evaluation and in advising planners and designers of promising development projects.

1.60 Agricultural development plans and investment programmes should make provision for the early implementation of those basic land improvement and soil conservation projects and facilities for waste disposal which individual farmers and agro-industries cannot afford to carry out by themselves.

1.70 An important part of the agricultural planning process and other aspects of rural planning should be carried out at the local level so as to involve the farming community and enlist their participation in improving the quality of rural life.

2. <u>To conduct selective base line surveys of agricultural areas where basic agricultural resources are known or suspected to be suffering environmental degradations</u>

2.10 Prior to selecting priority areas, collection and review of available basic land and water resource surveys, inventories and data should be made in order to identify specific sources of environmental degradation;

2.11 subjects for study include loss of soil productivity; loss of useful genetic resources; depletion of grazing lands; recurrent destruction of crops, livestock and wild herbivores by pests, diseases, or pollution; accumulation of harmful agricultural wastes; and indications of climatic changes.

2.20 More comprehensive interpretations of existing data should then be made to identify similar agricultural areas;

2.21 inter-relationships among ecological conditions, types and intensities of land use and management practices, and problems of environmental degradation should all be identified.

2.30 On this basis, priorities for urgent actions of conservation and protection of agricultural resources and for additional surveys and research should be established;

2.31 these should consider the areas where the productive capacity of the resources and the agricultural products are most affected or threatened by environmental degradations.

2.40 Capabilities of existing institutions should be strengthened in the light of the essential findings of these background basic resource and interpretative surveys for the purpose of undertaking the required action.

2.50 Additional inventories and surveys should then be continued by sectors in priority areas where critical conditions to land productivity have been specified.

2.51 These should be developed by successive stages of approximation and detail;

2.52 they should make provision for periodic joint compilation and interpretation, including consideration of environmental effects of agriculture on other resources such as air, water, aquatic resources and wildlife - thus aiming at following comprehensive natural resource assessment and management.

3. <u>To keep systematic records of environmental problems caused by or affecting agriculture using the above base line surveys</u>

3.10 The existing agricultural institutions (e.g. research institutes, field stations and other services) should provide the necessary network for these monitoring activities.

3.20 Special emphasis should be placed on surveillance of soil degradation and on early warning systems for pests, diseases and pollutants affecting crops, livestock and the quality of agricultural products.

4. <u>To strengthen basic agricultural research to improve ecological understanding</u>

4.10 Research should be undertaken in selected ecosystems and problem areas on the general subjects of:

4.11 the functioning and productivity of agricultural systems;

4.12 the processes of degradation of land resources and contamination of agricultural products;

4.13 the environmental effects of certain specific agricultural practices and agricultural inputs, particularly agro-chemicals;

4.14 the relationship of climate to the above items.

4.20 In addition, a variety of ecologically-sound management opportunities merit study:

4.21 the recycling of municipal wastes, including their detoxication, onto agricultural lands;

4.22 multiple cropping in the tropics, including considerations of crop combinations and sequences, cover crops, fertilization and weed control;

4.23 systems to re-utilize the wastes of agricultural runoff;

4.24 integrated pest controls, including combinations of regulated pesticide use, cultural controls, crop diversification.

5. <u>To direct the agricultural research services and field stations to incorporate environmental considerations into programmes of investigation and experimentation</u>

5.10 The findings of basic ecological research should be applied to the study, design, and experimentation of ecologically stable systems of land use and agricultural practices, particularly in tropical and subtropical areas, whereby:

5.11 the productive capacity of land resources can be maintained on a long-term basis;

5.12 wastes can be disposed of or recycled in these systems without harmful effects on natural resources or on the environment generally.

5.20 In testing various combinations of crops and/or livestock, agricultural inputs, and management practices and in attempting to maximize yields or economic returns, experiments and pilot areas on priority critical areas referred to before should be designed to assess:

5.21 possible environmental side-effects of run-off, erosion, and other forms of soil degradation and of the accumulation of harmful residues, especially those from agro-chemicals;

5.22 the technical ability of local farmers to introduce new land use practices without causing deterioration to agricultural resources and the environment;

5.23 the economic feasibility of implementing agricultural practices which can better protect the resources and the environment without adding to farm management costs. To this end, special investigations should be undertaken to evaluate the costs and long-term benefits of environmental protection practices in agriculture, including the intangible social benefits that may accrue from the soil conservation development process.

5.30 Agricultural research institutions should, wherever feasible, use radio-isotopes and radiation techniques to develop new, safer and more efficient management practices;

5.31 this applies particularly to the application of fertilizers, pesticides, and irrigation water and to the biological control of pests.

6. <u>To develop and facilitate information exchange and transfer of experience in agriculture within an ecological framework</u>

6.10 The transfer of information and experience in agriculture should be based upon similar ecological conditions, especially on climate and soil.

6.20 Within this framework, relevant and selected information should be made readily available to potential users (e.g. planners, extension services, farmers) in a form easily understandable and applicable, on:

6.21 soils, their characteristics, capabilities, and limitations for different uses;

6.22 genetic resources, their requirements, potential resistance to pests and other adverse factors;

6.23 agricultural practices most suitable for both increased production and minimum environmental damage, particularly soil conservation practices and integrated pest control techniques;

6.24 most appropriate methods of agricultural waste disposal and recycling under local conditions.

7. <u>To introduce environmental considerations into the programmes of agricultural education and training</u>

7.10 The focus on the importance of the new dimension on environmental assessment and management aimed at sustaining acceptable standards for the quality of life was prompted by the Stockholm World Conference on the Environment (1972). In this respect, more emphasis should be placed on the creation of an understanding of:

7.11 the vital role of agriculture for man's welfare and for the maintenance of environmental quality;

7.12 the environmental problems related to specific management practices, particularly those related to soil and water conservation and pest control;

7.13 the limits to the carrying capacities of natural resources under particular farming or grazing conditions. In this respect the delineation of the marginal projected deferment coupled with a listing of the practices on land management is crucial.

7.20 These considerations should be introduced at all levels of training and education.

8. <u>To introduce an institutional and legislative framework which accounts for the environmental dimensions of agricultural development</u>

8.10 Soil and agricultural institutions should be directed to consider the ecosystem as an operative unit in the management of air, soil, plant, and water resources;

8.11 land settlement, agrarian reforms, and land consolidation should recognize local diversities of soil and climate;

8.11.1 the extension and intensification of agriculture should be modified accordingly.

8.20 Land evaluation should serve as a basis for land zoning, land use legislation, licensing and regulations;

8.21 measure should be designed to respond to degradation resulting from misuse of croplands, misuse of agricultural inputs, and from the careless disposal of agricultural wastes.

9. <u>To provide incentives and assistance to farmers and agro-industries</u>

9.10 Measures could include, depending on a given country's social and economic system, credit, better marketing facilities, tax reductions or exemptions, and subsidies in cash or kind.

9.20 Such measures would induce or enable recipients to undertake necessary actions to prevent or correct environmental degradation of general public interest caused by their activities.

9.30 Examples would include soil and water conservation, use of more selective pesticides, and recycling of wastes.

10. <u>To establish or strengthen national programmes of conservation of soil resources</u>

10.10 According to local conditions and requirements, these programmes may place emphasis on one or more of the following areas:

10.11 rain fed crop lands, particularly dry farmed areas;

10.12 irrigated lands with salinization, alkali and waterlogging hazards;

10.13 erosion along rural roads and highways;

10.14 grazing lands, particularly in arid areas;

10.15 wind erosion, stabilization of sand dunes;

10.16 watershed protection and afforestation;

10.17 marginal lands, i.e. those areas falling between lands where intensive agricultural production is feasible and those unfit for agriculture and requiring protection.

10.20 The programme should be integrated with the actions proposed earlier on base line surveys, research, assessment of land capabilities, assistance to land use planning authorities, development of ecologically stable agricultural systems, soil conservation legislation, extension work and assistance to farmers;

10.21 as such, it will go well beyond the mere promotion of soil conservation, erosion control practices, and land improvement works.

10.30 A number of specific measures might possibly be employed:

10.31 erosion might be controlled through the use of various forms of mulches, primarily in the form of crop residues; engineering and agronomic techniques to stabilize the soil and lessen the erosive force of wind and water; control of fires; overgrazing, and deforestation; reseeding; and terracing;

10.32 salinity and alkalinity control might employ knowledge of a plant's salt tolerance, the salinity of the water used for irrigation, and the soil characteristics for adequate irrigation and leaching;

10.33 the leaching and depletion of soils particularly in the tropics might be reduced through controlling the intensity of agricultural use, by providing fallow periods, by introducing horticulture or pasturage instead of shortcycle crops, or by the use of appropriate fertilizers.

10.40 Particular attention should be given in erosion control programmes to reducing sediment delivery to streams, reservoirs, dams and other water bodies in order to control physical, chemical and biological effects of these sediments on water quality and aquatic resources.

10.50 A special fund for the conservation of national soil resources may be needed to provide the necessary focus and means of action.

10.60 National soil institutions should be strengthened by reinforcing the soil conservation services and establishing, where needed, special units for land evaluation which adopt the multidisciplinary physical resource/socio-economic interrelationship approach, the framework of which has been developed by FAO's Land and Water Development Division.

11. <u>To consider the possibilities of recycling agricultural wastes</u>

11.10 To the extent practicable and safe, animal or organic agro-industrial and municipal wastes could be used as fertilizers.

11.20 Likewise, crop residues could be used for composts or as animal feed.

11.30 In either case, the wastes or residues could be distributed to improve the structure and fertility of the soil;

11.31 attention must be paid to guard against contamination of the soil resource and the spread of infectious diseases.

11.40 Wherever not feasible, these wastes should be collected, treated and disposed of under controlled conditions in order to:

11.41 minimize pollution, contamination, fire and other hazards;

11.42 maintain the attractiveness and salubrity of rural lands and streams.

12. <u>To institute or reinforce national programmes to regulate the use of pesticides and other biocides and to develop integrated pest control</u>

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1976 Council, Fourth Session UNEP Nairobi.

APPENDIX I

PROGRAMME

Monday 22 November	
09.30	Opening of Consultation: Dr. F.W. Hauck, Officer-in-Charge, AGLS
	CONSERVATION PRACTICES IN AGRICULTURE Chairman: Dr. N. Gil
10.10 - 10.45	Soil conservation practices and erosion control in India - a case study Dr. D.C. Das
11.15 - 11.45	Traditional forms of land use in relation to soil erosion Prof. A. Young
11.45 - 12.30	Discussions
14.30 - 15.15	Land classification Mr. G.M. Higgins
15.20 - 16.00	Soil conservation as a protective measure against salinization Dr. F. Massoud
16.00 - 17.15	Discussions
Tuesday 23 November	CONSERVATION PRACTICES IN AGRICULTURE Chairman: Prof. N. Hudson
09.15 - 10.00	The role of soil conservation in watershed management on agricultural lands Dr. N. Gil
10.00 - 10.45	Role of cover crops in soil and water conservation Dr. B.D. Okigbo and R. Lal
11.15 - 12.00	Discussions
14.30 - 15.15	Studying patterns of soil erosion in Kenya Dr. T. Dunne
15.15 - 16.00	Soil erosion and reservoir sedimentation - case studies in Tanzania Dr. A. Rapp
16.30 - 17.15	Discussions

Wednesday 24 November	**FORESTRY: WATERSHED MANAGEMENT AND SOIL CONSERVATION** Chairman: Prof. A. Young
09.15 - 10.00	Upland conservation - an essential part of agriculture downstream Dr. S. Kunkle
10.00 - 10.45	Examples of soil and water conservation practices in North African countries - Algeria, Morocco and Tunisia Mr. B. Bensalem
11.15 - 12.00	Discussion
	GRASSLAND MANAGEMENT Chairman: Prof. A. Young
14.15 - 15.00	Soil and water conservation as an aid to range management Dr. J. Naylor
15.00 - 15.30	Discussion
15.45 - 16.30	Grassland management in relation to soil conservation and erosion control in developing countries Dr. T. Ionesco
16.30 - 17.15	Discussion
Thursday 25 November	**RESEARCH, ORGANIZATION, EDUCATION, EXTENSION AND ENVIRONMENT** Chairman: Dr. D.C. Das
09.15 - 10.00	Research needs for soil conservation in developing countries Prof. N. Hudson
10.00 - 10.45	Development of soil and water conservation service for developing countries - specific requirements and possibilities for assistance Dr. N. Gil
11.15 - 12.15	Discussion
14.15 - 15.00	Training, extension and implementation of soil conservation programmes in developing countries Mr. O. Jones
15.00 - 16.00	Environmental perspectives of land use policy in relation to soil and water conservation Dr. L. Kadry
16.00 - 16.30	Discussion
16.30 -	Working groups
Friday 26 November	
09.15 - 11.45	Meetings of working groups
14.15 - 15.15	Chairman: Dr. F.W. Hauck Report of the working groups a) working group on practical aspects b) working group on organization, training, extension and research.

APPENDIX II

LIST OF PARTICIPANTS

EXPERT CONSULTATION ON SOIL CONSERVATION AND MANAGEMENT IN DEVELOPING COUNTRIES

Rome, 22-26 November 1976

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