FAO SOILS BULLETIN 30

soil conservation
for developing countries

FOOD AND AGRICULTURE ORGANIZATION
OF THE UNITED NATIONS ROME

FOREWORD

In 1948, three years after its establishment, the Food and Agriculture Organization of the United Nations (FAO) published "Soil Conservation, an International Study" (Agricultural Study No. 4), which focused attention on the worldwide nature of the soil erosion problem. Further publications have been issued from time to time on specific aspects of soil erosion and its control. Among these are "Soil Erosion by Wind and Measures for its Control on Cultivated Lands" (Agricultural Development Paper No. 71 of 1960); "Soil Erosion by Water - Some Measures for its Control on Cultivated Lands" (Agricultural Development Paper No. 81 of 1965; "Guide to Sixty Soil and Water Conservation Practices" (Soils Bulletin No.4 of 1966) and "Legislative Principles of Soil Conservation" (Soils Bulletin No. 15 of 1971.

In view of the need to substantially increase production from areas under traditional subsistence agriculture in the developing countries, a particular study has been made of the problem of soil conservation in areas under shifting cultivation which account for 30 percent of the world's exploitable soils, and 40 percent of the exploitable soils in Africa. An FAO/SIDA/ARCN Regional Seminar was held on this important subject in Nigeria in 1973 and the results are published in "Shifting Cultivation and Soil Conservation in Africa" (Soils Bulletin No. 24 of 1974).

The purpose of this Soils Bulletin is to summarize the soil erosion problem and to focus attention on remedial measures available with particular reference to the lands under traditional forms of agriculture in the developing countries. It is hoped that the Bulletin will be of assistance to field workers of national, international and bilateral aid agencies working in areas of limited resources.

To be fully effective, the field worker needs the help and support of national land use, conservation, research and administrative organizations in the country in which he is working. Thus reference is made to the essential organizational and legislative measures necessary for this purpose.

It is hoped therefore that this Bulletin will be of help, not only to field workers but also to research workers and government officials involved in the framing and execution of soil conservation policy in developing countries.

ACKNOWLEDGEMENTS

The author wishes to acknowledge assistance received from the following organizations, who granted permission to use copyright materials in this publication.

National Institute of Agricultural Engineering,
Silsoe, Bedford, U.K.

B.T. Batsford, London.

Ministry of Overseas Development, Land Resources
Division, Surbiton, U.K.

United States Department of Agriculture, Soil Conservation
Service, Washington, D.C. U.S.A.

University of Uppsala, Department of Physical Geography,
Sweden.

Thanks are also due to the many individuals who assisted through discussions, guidance and encouragement, in particular:-

Professor N. Hudson and his staff at the National
College of Agricultural Engineering, Silsoe, U.K.
and the staff of the Intermediate Technology Development
Group located there.

Mr. J. Hawkins, Mr. R. Bell, and Mr. D. Sutton at
the National Institute of Agricultural Engineering,
Silsoe, U.K.

Mr. A.J. Smyth and his staff at the Land Resources Division,
Ministry of Overseas Development, Surbiton, U.K.

Dr. F.W. Hauck and Dr. F.I. Massoud of the Soil
Development and Conservation Group of FAO in Rome.

Special thanks are due to Mr. Orville Jones of the USDA Soil Conservation Service presently on a special soil degradation assessment project with FAO in Rome, for his suggestions and final review of the manuscript.

TABLE OF CONTENTS

PART 1 - SOIL EROSION

PART 11 - SOIL CONSERVATION

LIST OF TABLES

LIST OF FIGURES

FIGURE NO. | Page

FIGURE NO. | Page

INTRODUCTION

The care of the soil is essential to the survival of the human race. It provides most of the food required, fibres for clothing and wood for building materials. And yet, in many parts of the world, the soil has been so damaged by mismanagement and abuse that it will never again be able to produce food, let alone fibres and other industrial crops, at least not in the foreseeable future. This maltreatment has led to soil erosion on a vast scale, that is, the physical loss of the upper layer or top soil, the most vital part necessary for healthy plant growth. Once this top layer has been lost, it has for all practical purposes gone for good. For example even under natural conditions of cover it takes from 300 to 1 000 years or more to generate an inch of top soil, and it would need 2 000 to 7 000 years to generate seven inches (1).

Historical evidence indicates that in the eastern Mediterranean region during Roman times millions of hectares of land became desert; in China vast areas became eroded and abandoned, and as recently as 1934 records indicate that the Yellow River carried silt washed down from cultivated lands equivalent to soil one metre deep over 145 000 ha. In Latin America there are densely populated areas where the soil is very susceptible to erosion and losses have been so high as to place at least three countries there among the low-calorie areas of the world.

Severe soil erosion has taken place in advanced countries such as the U.S.A., in relatively recent times. By the 1930's it had been estimated that over 400 million hectares or more than half of the entire land area of that country was already affected by soil erosion in one way or another. Once recognized this situation sparked off intense research into the causes and results of soil erosion (see Chapters 2 and 3) and the preventive and remedial measures necessary. These are now well understood, and much of the damage caused in the past has been rectified, but at enormous expense. Nevertheless it is already too late to save 40 million hectares of arable land which was damaged beyond practical repair. Among the more important lessons learnt was that the problem of soil erosion is not just a physical one. There are social and economic influences which have a significant bearing on the degree of erosion which can take place and on the effectiveness of measures to combat it.

At a time of rapidly increasing world population and increasing food shortages it is even more obvious now that every effort must be made to protect the soil in order to increase food production. It is inevitable that there will have to be a marked increase in production in areas of the world practising traditional subsistence forms of agriculture. The soil erosion problem is of particular importance in the case of shifting cultivation which is practised on about 30 per cent of the world's exploitable soils, in Africa, Latin America, Oceania and South East Asia. (See Chapter 4.)

As soil erosion is a national problem the remedy lies in the application of soil and water conservation practices through a national soil conservation programme. However the farmers themselves have to carry out the necessary practices, on their land as part of their farming system. For this purpose they need assistance through education, survey and machinery services, credit facilities and perhaps subsidies because even simple practices need skill, knowledge and equipment which they may not have, while the more complex practices need extra power and finance beyond their normal resources. Therefore there must be an organization to provide the education and other practical assistance necessary through some form of specialized service, such as a soil conservation service. As soil conservation is an integral part of good farming and land use, it follows that such services should be supported by, and preferably integrated with national agricultural, water and forestry institutions under one Ministry. The dissemmination of knowledge and the discussion of problems and remedies in the field takes place between the farmer and the extension worker. It follows that the extension worker himself needs specialized training and experience, integrated with a sound agricultural and land use background. (See Chapter 5.)

Government legislation can encourage or discourage good farming and conservation practice depending on priorities selected. The framing of legislation is not an easy task because of conflicting interests, and the balancing of short term economic goals with long term protection of the soil. The problem is of particular interest to developing countries whose economies are based mainly on agriculture. In these countries the priorities are easier to define because of the need to increase production and the standard of living of the peoples largely from the products of the soil. (See Chapter 5.)

Developing countries have the opportunity to learn, not only from the mistakes of others but also from farmers, field workers and research workers in various parts of the world who have developed conservation measures to suit particular conditions. Many of these measures are simple and inexpensive, and provided they be applied in time are effective. Such systems and practices developed in isolation for local conditions may be suitable for similar conditions elsewhere. (See Chapter 6.)

2. FACTORS INFLUENCING THE RATE OF EROSION

2.1 THE MEANING OF SOIL EROSION

2.1.1 Normal Erosion

Erosion is a continuous process which is responsible for the changing pattern of the earth's surface. It is caused by water, wind, temperature changes and biological activity. When this process takes place without the influence of man it is known as normal, geological or natural erosion. Where there is a dense natural protective cover to the soil, such as grass, shrubs and trees, erosion takes place but it is regarded as normal because the soil is usually regenerated by natural means at the same rate as it is removed. In other words, the soil and vegetation are in a state of balance.

2.1.2 Accelerated Erosion

As soon as the natural protective vegetation is disturbed by, for example, cultivation, grazing or burning, the natural balance is upset and the soil becomes exposed to the direct action of the two most potent causes of erosion, water and wind. Under these conditions the soil can be washed or blown away at a faster rate than it can regenerate, resulting in a net loss of soil. This is known as accelerated erosion, and what is generally meant by the term Soil Erosion. The soil which is lost by soil erosion is transported, either to some other place where it is not wanted or to the sea down swollen rivers, and streams. The obvious signs of severe soil erosion are often dramatic, such as gaping gullies, the exposure of bedrock, and the silting of rivers and dams. Less obvious signs on farms, range and forest lands are decreasing crop yields and diminishing water supplies.

The degree to which soil erosion as defined above takes place on cultivated lands is influenced by a complex mixture of physical factors, such as the nature of the soil, slope of the land, cultivation practices and climate; also by economic and social factors.

2.2 NATURE OF THE SOIL

Soils differ in characteristics depending on their parent materials and the extent to which they have developed under the influence of climate and natural vegetation, a process known as weathering. Some soils are inherently more susceptible to erosion than others or to put it another way, some are more resistant than others. This factor, described as erodibility, is very difficult to measure quantitively because of the many variables involved, not only when the soil is in its natural state, but particularly after it has been subjected to the influence of man.

There are however properties of soils which in combination affect erodibility, such as the physical quality of texture and structure, the chemical composition, the extent of weathering and the content of organic matter.

Texture refers to the proportion of small, medium or large particles in a sample of soil. The smallest particles are clays and the largest small stones or gravel. For purposes of classification the various particles are described and defined in size groups or ranges. There are several systems of classification in use, but the International System is shown in Table 1 as an illustration :-

TABLE 1

International System of Soil Texture Classification

Description	Size range in mm
Clay	less than 0.002
Silt	0.002 - 0.02
Fine sand	0.02 - 0.2
Coarse sand	0.2 - 2.0
Gravel	more than 2.0

Structure refers to the arrangement of these individual particles in the soil into separate aggregates of different size and shape, varying from small crumbs up to large lumps or clods. The form of the structure is in turn controlled by interactions due to the chemical composition, particularly with regard to the molecular ratio of silica to clay. This ratio can be estimated by chemical analysis and it gives some indication as to whether the soil is old and well weathered or is relatively recent in development. The older well weathered soils tend to be more resistant to erosion than those which are only slightly weathered. The clay fractions have the capacity to absorb water and link the soil particles together. If there is a large proportion of clay present and the soil is allowed to dry out it sets into a hard impervious mass, or on shrinkage develops deep vertical cracks.

Organic matter in the soil can absorb and store water to a greater extent than the inorganic fractions and is better at forming aggregates. Organic matter is of great importance because of its ability to produce a soil with an open, porous, but water retentive structure; it acts like a sponge, taking in and retaining water and releasing it as required by the plants. Soils with this kind of structure are very resistant to erosion. Conversely, nearly all soils with little or no organic matter are very susceptible to erosion.

2.3 SLOPE OF THE LAND

The slope of the land, that is its gradient, is an important factor affecting the rate of erosion. Land which has any slope at all, sufficient to allow water to run down it, may be subject to erosion. If the slope is steep it can be expected that excess water from rainfall will run down at a higher velocity than a gentle one and cause more serious erosion. The length of the slope is also important, because it can be expected that the longer the slope, and assuming the same rate of rainfall, the greater will be the volume of excess water accumulating upon it, all of which must run down the slope at ever increasing volume and velocity. From the soil conservation point of view it is wise to recognize this relationship and there is ample evidence of serious damage on sloping land where it has been ignored. However, it is not possible to predict erodibility on angle and length of slope alone. Other factors which must be considered are the kind and density of vegetation, the nature of the soil, and the amount and intensity of rainfall. For example, a long and relatively steep slope covered with a good pasture or dense forest and undercover may not suffer from erosion at all, even under heavy and intense rainfall. On the other hand a gentle and short slope with only a widely spaced cover of plants may suffer very serious damage under the same conditions of rainfall, particularly if the soil is inherently susceptible to erosion.

2.4 CULTIVATION PRACTICES

The combined influences of soil and slope on the rate of erosion are in turn modified by the cultivation or farming practices employed - the way in which crops are grown, the livestock raised and the land treated by tillage and other means. All plants, animals, soils and tillage implements have characteristics which can be utilized in various ways, some leading to soil erosion and poor yields, others to soil conservation and high yields. Some important examples are mentioned here.

2.4.1 Crops

The rate of erosion is reduced to the minimum when the soil is completely covered by vegetation. Pasture plants grow so close together that the soil is very efficiently protected from both water and wind erosion. Well managed pasture and grass-lined waterways and drainage channels thus exhibit some of the best anti-erosion measures which can be devised, and they are applicable over a wide range of soils, slope and climatic conditions.

In the case of maize there is a considerable space between each plant which must be weeded. To obtain maximum yield it is necessary to maintain the optimum plant population and also an optimum spacing between and within rows. It has been found that the spacing within the row can be as close as 15 to 23 cm depending on variety, much closer than was at one time thought possible, without reduction in yield (2). (See also Chapter 6.) This characteristic is very important from the soil conservation point of view. If the rows be planted up and down sloping land, and the soil is erodible, serious erosion may occur from run-off water rushing down the strip of bare soil during heavy rainstorms. On the other hand, if the rows be planted on, or nearly on, the contour the rate of erosion will be greatly reduced because the relatively closely spaced plants in the row will tend to check the velocity of run-off and allow more water to percolate into the soil.

The same principles apply to cotton, where it has been found that the spacing in the row can be closed up to 15 to 30 cm in the row depending on variety and time of planting.

If the crops be grown on ridges along the contour the erosion hazard from run-off can be reduced still further. In the case of cotton this coincides in most cases, and certainly on light sandy soils, with higher yields than those obtained by flat cultivation (3).

Perennial crops, such as castor, coffee and fruit trees because of their size have to have much wider spacings between plants. Thus juggling with the spacing to produce a barrier to soil wash along the row is not possible. Other methods for protecting the soil between plants may be employed such as mulching, terracing or both. Providing such measures are carried out correctly the rate of soil erosion will be reduced to an acceptable level.

These few examples are touched on to illustrate that the crop itself is not the culprit if soil erosion occurs (a popular belief held in the past), but the way it is grown and managed.

2.4.2 Animals

All kinds of farm livestock, such as pigs, cows, sheep and goats can cause soil erosion. Cows, sheep and goats can destroy good pasture by over grazing and trampling. Goats are much maligned because they not only eat and trample all the grass, but browse on shrubs and trees as well until there is not a green leaf or succulent branch left. (See Figure 1.)

Soil erosion due to overgrazing results from technical and socio-economic factors, such as poor land management, uneven distribution of animals, too many animals for the carrying capacity of the grass; or social factors such as the number of animals being the criterion of wealth (irrespective of their condition). Also the continuous passage of herds of animals from one grazing area to another, or to market, forms bare paths and tracks which can soon develop into gullies through erosion (see Figure 2), while concentrated grazing in the vicinity of water points, dams, lakes and rivers causes severe run-off and siltation of the water supply.

Again, these results are not the fault of the animals, but the way in which they and the land are managed.

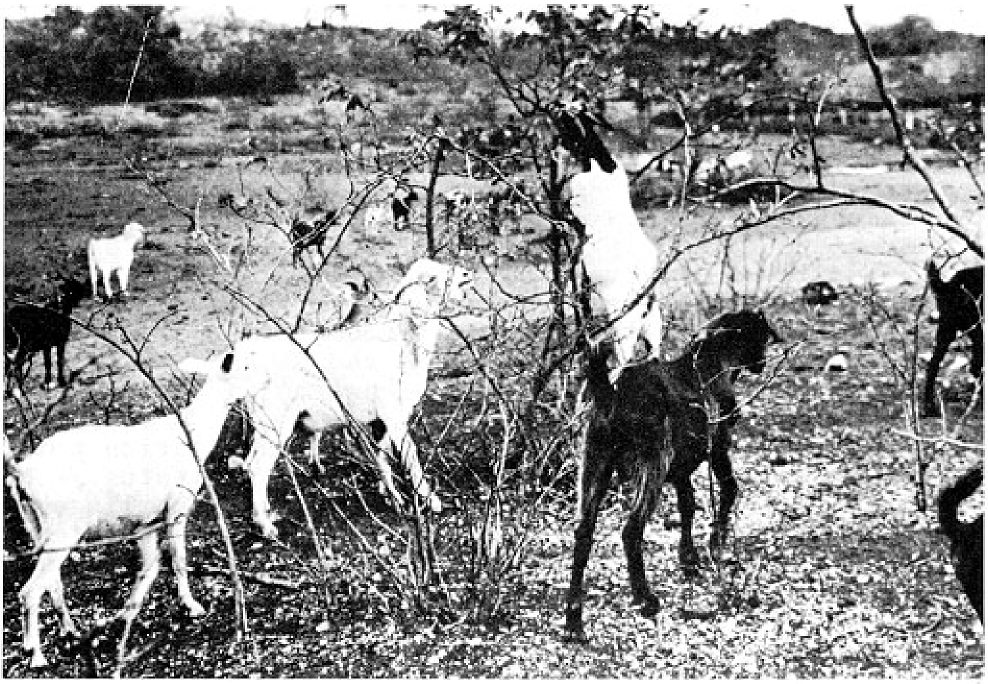

FIGURE 1. - Results of uncontrolled grazing by goats. (Copyright: H.H. Bennett, U.S.A.)

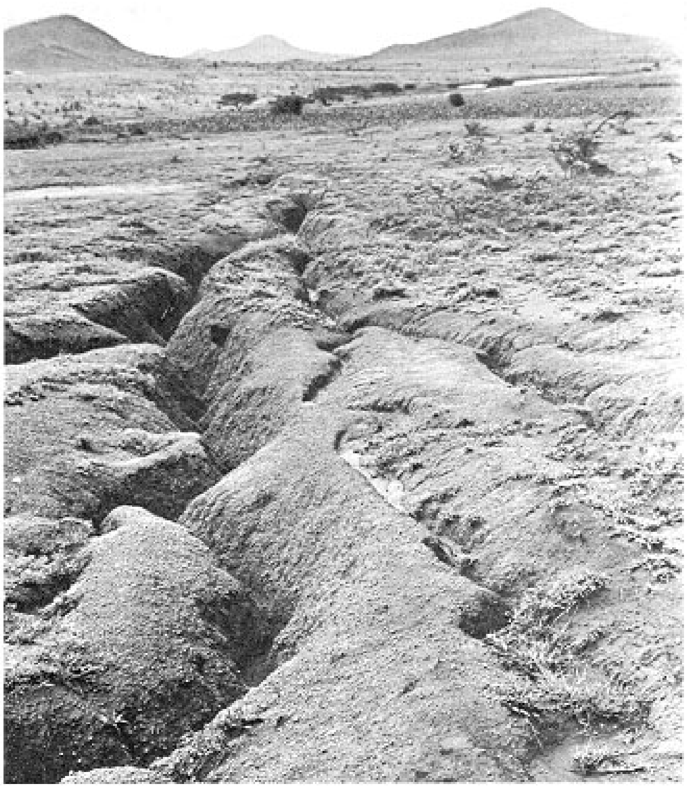

FIGURE 2. - The continuous passage of animals along the same route leads to gullying (Tanzania: Photo by H. Murray Rust)

2.4.3 Tillage

Tillage practices and implements have been developed over the centuries to manipulate the soil with the intention of improving conditions for plant growth. The earliest implements were pointed sticks used by hand, later developed into a variety of hand hoes with iron blades and iron-pointed wooden ploughs pulled by animals. In many parts of the developing world indigenous implements are not much different from the primitive types and many millions are still in daily use. The use of these implements has tended to cause less damage to soil structure than the multitude of more sophisticated implements such as multi-furrowed ploughs and discs, harrows and cultivators recently developed by industrial nations.

The importance of tillage from the soil conservation point of view is its effect on soil structure and moisture status. Modern high powered machines are capable of more intensive tillage than the early hand and animal operated implements and can be a potent force for soil destruction and erosion if used in the wrong way or under the wrong conditions for the machine. Many of these machines were developed for conditions in the temperate zones and when used in the tropics, and particulayly in the semi-arid zones, they often produced undesirable results. Soils were pulverized to dust resulting in serious wind and water erosion, while the machines themselves wore out quickly due to the effects of dust and abrasive soils. It was "back to the drawing board" for all concerned, with a hard look at both tillage requirements and machine design for tropical soils. Although there are advocates of deep ploughing and the incorporation of organic residues for soils in the humid tropics, the concept of minimum tillage and mulching is now gaining considerable support, especially for soils of the semi-arid zones. (4)

There is little doubt that tropical soils cannot stand up to intensive tillage and mismanagement to the same extent as soils of the temperate regions. Therefore, great care must be exercised in the use of high powered machinery, particularly on sloping land.

Irrespective of the factors discussed above, when ploughing and other tillage operations are carried out up and down the slope of the land in high rainfall areas in the tropics the result is serious soil and water loss. To reduce the risk of erosion, all tillage operations must be carried out along the contour or at least across the slope and supported according to need, by additional agronomic and mechanical measures. Once again, it is not the machine which causes erosion, but the way it is used. (See Chapter 6.)

2.5 CLIMATE

The main elements of climate which affect the rate of erosion are rainfall, wind and temperature. Figure 3 shows generally where most of the rain falls. It will be noted that the highest rainfall is concentrated within the tropical zone.

Figure 4 shows the areas of the world which are most susceptible to rainfall erosion. This includes all lands receiving medium to high rainfall within latitudes approximately 42° north and south.

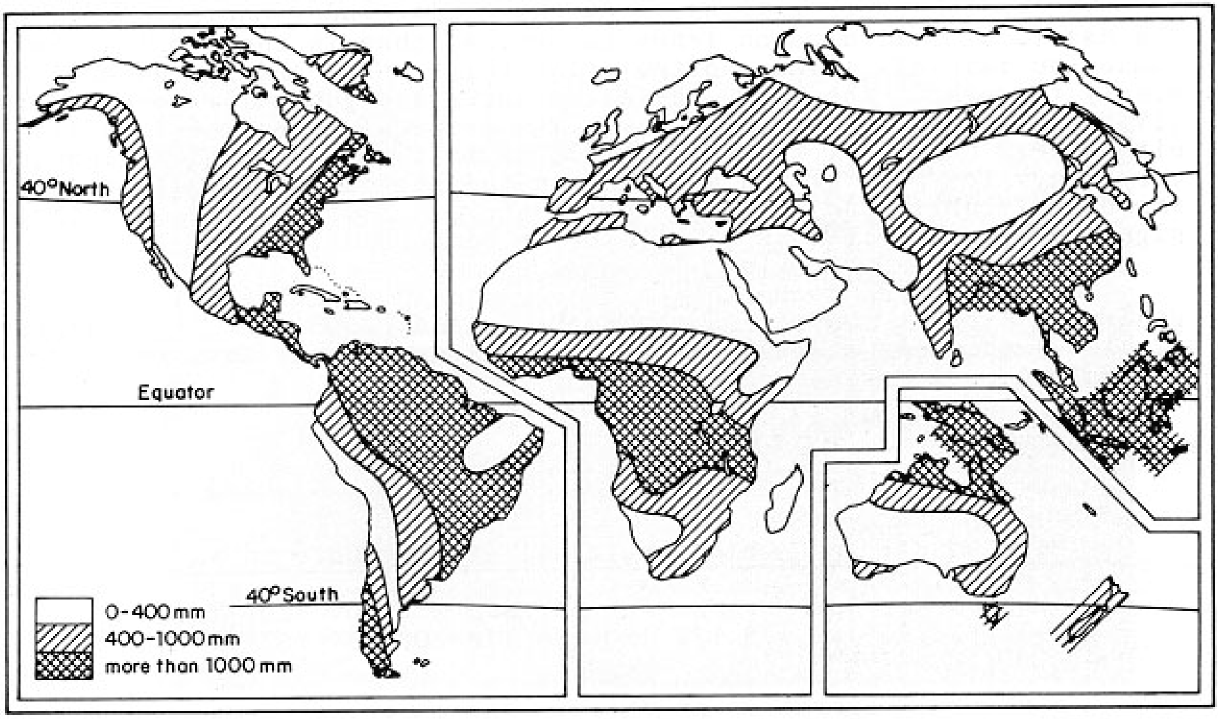

FIGURE 3. - World map of mean annual rainfall.

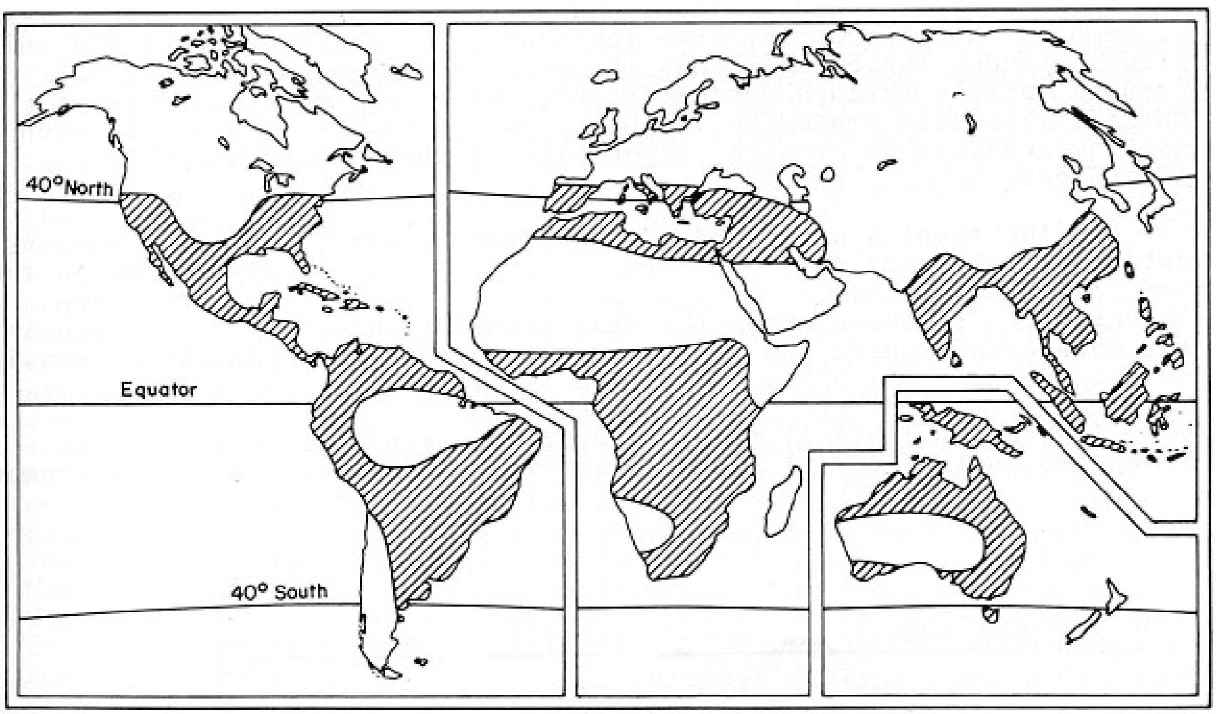

FIGURE 4. - World map of distribution of rainfall erosion.

In the temperate regions in excess of latitudes approximately 35° the hazard of soil erosion tends to be less than in the tropics, because the rainfall is more often relatively gentle and spread more evenly throughout the year, while the soils are generally more absorptive and resistant to erosion. In the tropical zones the rainfall is either very heavy all the year round, as in the Equatorial regions, or very heavy for part of the year, as in the seasonal rainfall areas immediately north and south of the Equator. Some examples and their significance are given in the following paragraphs.

In the regions along the Equator the mean annual rainfall generally exceeds 1000 mm and in parts exceeds 2000 mm. In Singapore (Table 2) the mean annual rainfall is 2414 mm but the mean monthly rainfall in all cases exceeds 170 mm.

TABLE 2

Mean annual and monthly rainfall at Singapore in mm

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
251	173	193	188	173	173	170	196	178	208	254	257	2414

The natural vegetation in these areas comprises dense evergreen forest which breaks the force of the rain and provides ground cover. Provided the forest is left alone, the danger from soil erosion from rain and resultant run-off is negligible. As soon as the vegetation is removed for human settlement and cultivation the soil is vulnerable to erosion. Furthermore, the temperature in these areas is high all the year round. Thus, when the shade provided by the forest is removed through cutting down the trees, the temperature of the soil rises. Under these conditions the organic matter in the soil decreases rapidly through decomposition, while the leaching of plant nutrients is accelerated by the heavy rain, resulting in a soil even more susceptible to erosion, especially if the land is sloping. (See Figure 5.)

In the tropics north and south of the Equator, and those regions extending to approximately latitudes 42°, additional dimensions in the rainfall pattern have to be considered - seasonal distribution and intensity. In these areas the mean annual rainfall is lower than in the equatorial zones, but this does not mean that the danger of erosion due to rainfall is less - in fact it is often more.

In Bombay (Table 3) the mean annual rainfall is lower than at Singapore, but 94% of it falls during the four months June to September.

TABLE 3

Mean annual and monthly rainfall at Bombay in mm

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2.5	2.5	2.5	2.5	17.8	485	617	340	264	64	12.7	2.5	1813

FIGURE 5. - Clearing and burning of dense forest cover, leaving the soil open to rapid decomposition of organic matter, leaching of plant nutrients and erosion from heavy rainfall. (Sumatra: FAO photo by H. Hull)

Other important factors to note in Table 3 are that the rainfall for each of the months June to September exceeds the rainfall for any month at Singapore, while there is a distinct dry season extending from December through to April. Thus, areas of high seasonal rainfall in the tropics are not only very vulnerable to water erosion during the monsoons or "rains", but are also subject to wind erosion during the long dry season.

In considering the full effect of rainfall on erosion even monthly figures of precipitation are not sufficient. The amount of damage which can be done to the soil is dependent in addition on several other factors - the amount of rain which falls during each storm, the frequency of storms, and the rate at which it falls, (intensity). In seasonal rainfall areas in the Tropics intensities around 150 mm per hour are quite frequent, and even 340 mm per hour have been recorded. (5). Modern rain gauges are capable of measuring total rainfall and intensity. From the results tables or graphs can be prepared to give a picture of all these rainfall events. The graph in Figure 6 is an example. It has been prepared on the basis of rainfall records available at Morningside, near Morogoro, in Tanzania, at Latitude 6° 51' South, and refers to an eight year period from 1 August 1963 to 31 July 1971. (6). During this period the mean annual rainfall was 2465 mm. The seasonal distribution of the rainfall is clearly shown, with most of the rain falling in March to May, (locally known as the "long rains") with another peak over October, November, December, (the "short rains"). The wettest month April often has more than 500 mm of rainfall.

The monthly mean intensity of rainfall given by the ratio of total rainfall to duration (see Fig. 6) was highest in March (7.5 mm per hour) and lowest in June (3.5 mm per hour). .... Of greater hydrological significance than the mean storm intensity are the frequency and duration of high intensity fall. ..... The highest recorded half-hour intensity during the 8 year period was 97 mm per hour. Half-hour intensities of 50 mm per hour were equalled or exceeded on the average 3 times a year. The highest recorded one-hour intensity was 65 mm. (6)

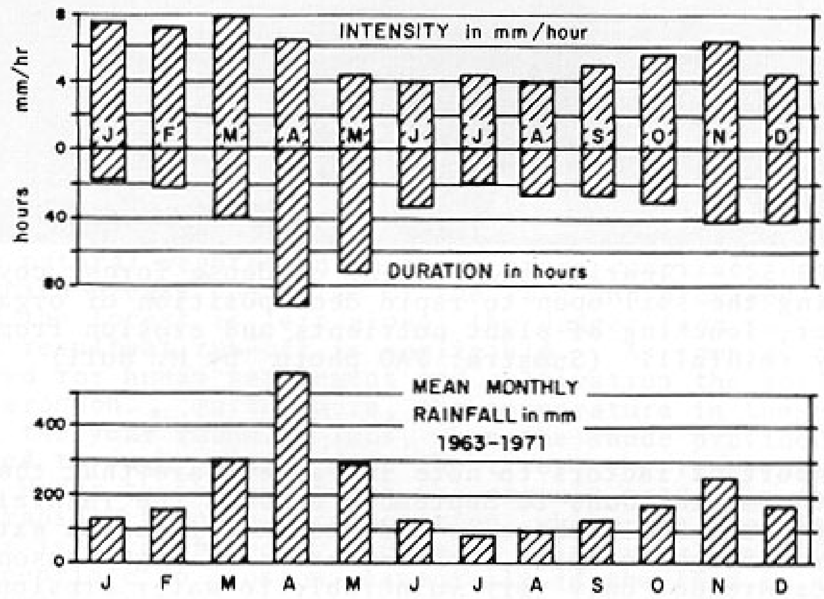

FIGURE 6. - Mean monthly rainfall, duration and intensity at Morningside Weather Station, Tanzania (6)

FIGURE 7. - This field lost 50 mm of top soil over its whole surface during a heavy rainstorm of only a few hours. (Tanzania: Photo courtesy of National Institute of Agricultural Engineering, U.K.)

Rainfall records alone cannot be used to predict precisely what will happen on the land under field conditions. The final result, in terms of soil loss, depends on the interaction of all those factors of soil, slope, vegetation and cultivation practices touched on in 2.2 to 2.4 above.

Quantitative prediction of soil loss under these circumstances is very difficult, but a theoretical demonstration of the relationship is possible. For this purpose it is necessary to define the power of rain to erode, designated as its erosivity, and the susceptibility of the soil to erosion, designated as its erodibility, (see 2.2). The erosivity of the rain can be expressed in terms of its kinetic energy, and the erodibility of the soil in terms of characteristics which can be measured in a laboratory. Erosion is then a function of Erosivity and Erodibility.

All those factors which include variables of soil, slope, cover and the way the land is treated are incorporated in an expression known as the Universal Soil-Loss Equation, (5) (22). The full equation is :-

$$A = R \times K \times L \times S \times C \times P$$

where A = soil loss

R = rainfall erosivity function

K = soil erodibility function

L = length of slope function

S = steepness of slope function

C = crop management function

P = conservation practice function

The long dry periods in these seasonal rainfall areas give rise to another problem. The natural vegetation ranges from grassland or savannah which provides good cover, to scrubland which provides only poor cover. Large areas are under intense cultivation, or traditional forms such as shifting cultivation. Furthermore these areas may be subject to high winds during the dry season. Thus, where the cover is poor, either due to the natural vegetation or the system of cultivation, there is the danger of wind erosion.

The semi-arid and desert areas of the world are of course vulnerable to wind erosion at any time, particularly where the soil is loose, a familiar result being sand or dust storms. Dust storms can cause much discomfort and damage to human habitation and crops up to thousands of miles away.

Wind is not the only problem in dry areas. There are vast expanses of the world within the latitudes under discussion, which are irrigated from groundwater or surface water. Temperatures are usually high, and this means that evaporation is high. Unless adequate precautions are taken, salts toxic to plants are brought up from below and concentrated in the upper layers of the soil. This problem is therefore very much the concern of the soil conservationist.

Semi-arid and arid areas are also subject to erosion by water, particularly low lying plains which fan out from a range of mountains. There may be heavy seasonal rainfall in the mountains, the run-off from which suddenly rushes down previously dry streams and river beds in great volume, as flash floods. These floods can cause extensive damage to habitations, soils and crops in their path, while the mountains themselves and the fan slopes become increasingly gouged into deep gullies.

2.6 SOCIO-ECONOMIC FACTORS

The most important effect of adverse economic factors on the business of farming, particularly in areas vulnerable to soil erosion, is the damage which can be caused to the land. If a shop-keeper or manufacturer suffers a run-down in his business, or goes bankrupt due for example, to a change in the market situation, or a shortage of labour, raw materials, credit or inefficiency, the land on which the buildings stand is still there and in the same condition as before. It may be used again for an alternative enterprise, with new finance and management, to meet new market conditions.

In farming the run-down of the business or bankruptcy may arise for similar reasons, but there are additional factors - such as vagaries of climate and, perhaps, soil erosion. Where severe soil erosion has taken place the damage suffered by the land may be irreversible, or the cost of reclamation too great and without hope of an economic return. In the extreme case no further economic crop or animal production will be possible on that land.

Like any other enterprise, the returns from farming must be sufficient to cover daily living and other expenses such as purchase of seeds, fertilizers, fuel and wages. It must also produce enough to invest in measures to conserve and improve the soil and to increase output. This situation is much more difficult to achieve on small farms and on poor land, than on large farms and on good land. On soils subject to soil erosion there is the added need for investment in, and maintenance of soil conservation measures. In many parts of the developing world there are millions of farmers on small farms of medium to poor land subject to soil erosion. The productivity is low due to a whole host of factors such as lack of good seed, fertilizers, water, suitable machinery, social customs, ignorance, superstition, credit facilities, markets, etc. On top of this many of the crops which they grow, particularly grain and other food crops command low prices, both locally and on the world market. The scale of production and the yields are too low to cover the investments needed to raise production. It is a vicious circle, which has led in so many instances to abandonment, and complete loss of the productive capacity of the land. Governments can also aggravate this situation by employing unrealistic taxation policies, or subsidizing certain crops to meet immediate short term requirements which lead to a detrimental change in land use by the farmers.

Security of land tenure is vital for a farmer. If he feels that he is insecure, whether he be an owner, tenant or otherwise in occupation of land, he will tend to "mine" that land until it is no longer productive, and then move on elsewhere and repeat the process.

3. RESULTS OF SOIL EROSION

3.1 SOIL EROSION BY WATER

The general relationship between amount, distribution and intensity of rainfall and the hazard of soil erosion has been discussed in Section 2.5. The actual process of erosion by water is activated by the force of the rain and also by run-off arising from it.

The impact of raindrops and flow of run-off over the surface of the land causes detachment of soil particles and their transportation downslope and downstream. The action of a single raindrop falling on bare soil resembles the action of a bomb. (Figure 8.)

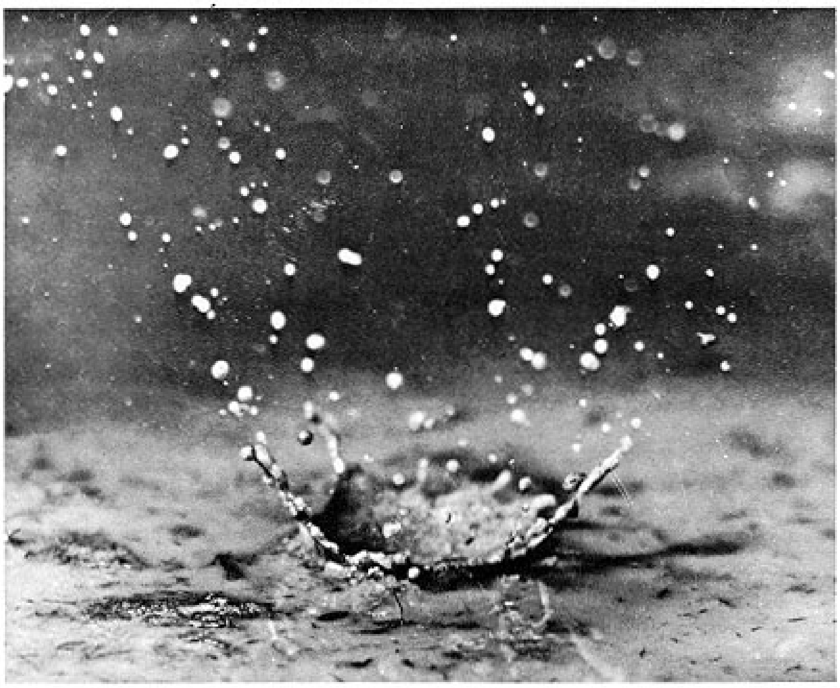

FIGURE 8. - Action of a single raindrop falling on wet bare soil. (Photo by USDA Soil Conservation Service.)

The energy released by thousands of relatively large raindrops at high velocity during an intense tropical storm can be imagined. (Figure 9.)

This release of energy causes dispersion of soil particles and destruction of aggregates. The very small particles thus dispersed (mostly clay) seal up pores in the soil surface. Thus as the pores fill up, the absorptive capacity decreases and the surplus water moves down-slope, carrying the smaller splashed particles with it.

FIGURE 9. - Action of a multitude of raindrops on bare soil during a heavy rainstorm. (Photo USDA Soil Conservation Service (7).)

The general pattern of events is a net loss of soil in uplands and a net accumulation of fertile soil in deltas. As erosion continues, run-off collects in small rills or channels where its erosive and transporting powers are enormously increased. The rills become gullies and the gullies become progressively deeper and wider. If the process is allowed to continue all the top soil may be removed. (Figures 10 and 11.)

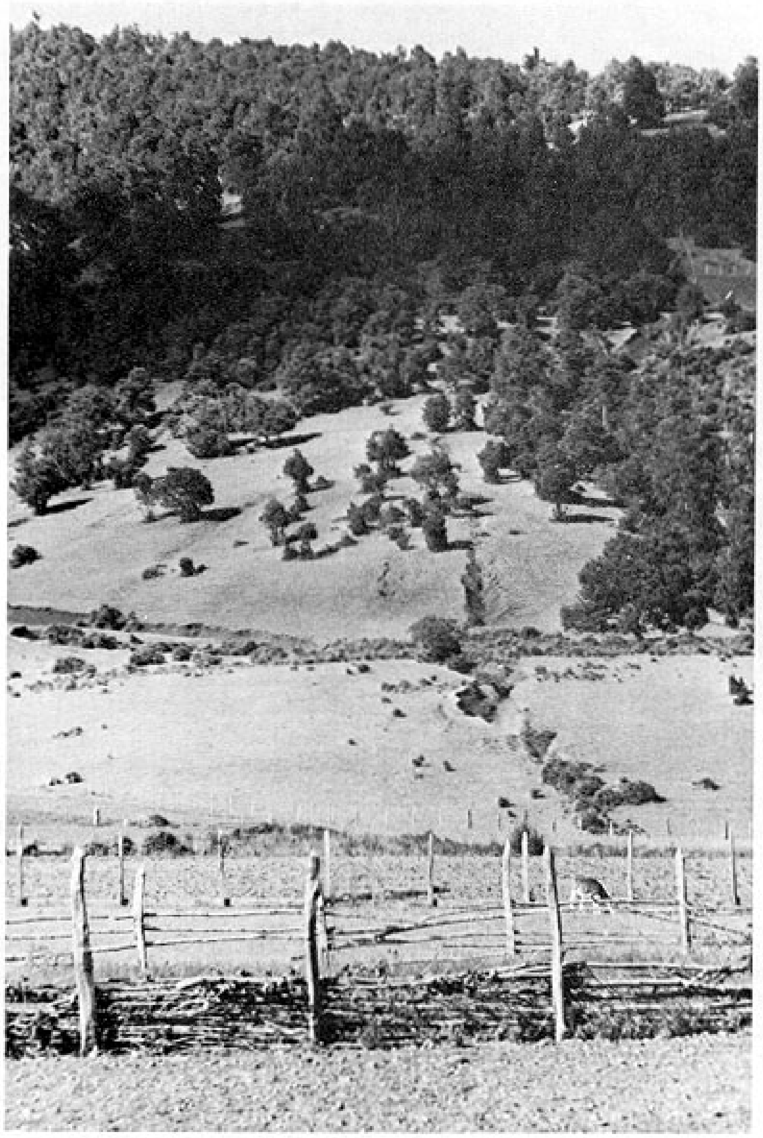

FIGURE 10. - The start of gully erosion on a recently cleared hillside. (Chile: FAO photo by H. Hull)

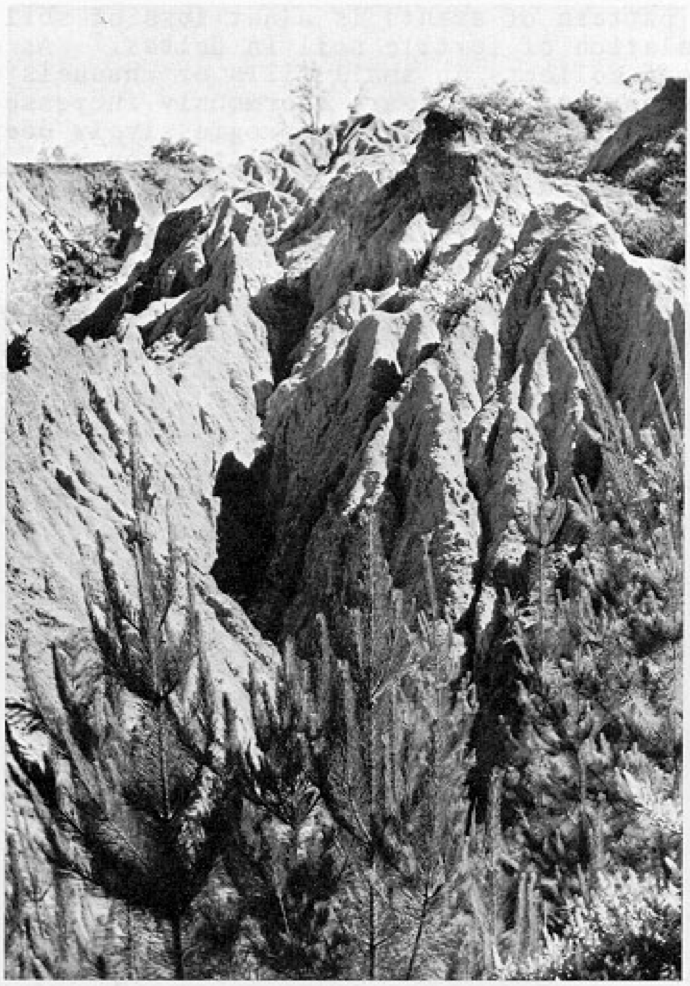

FIGURE 11. - An advanced stage of erosion due to rainfall impact and run-off. The pine trees in the foreground have been planted to halt the further spread of the destruction. (Chile: FAO photo by H. Hull.)

The sediment transported in this way may enter natural or man-made lakes where it will settle out due to a reduction in the velocity of the water flow, resulting in loss of storage capacity in the reservoir. (Figure 12.)

Huge loads of the products of erosion, i.e. sediment, are carried by gullies, streams and rivers to lakes, dams or, finally, to the sea, but local deposition of sediment can cause great damage to growing crops, and silt up drainage and irrigation channels, increasing the danger of flooding. (Figure 13.)

FIGURE 12. - River carrying thousands of tons of sediment eroded from cleared and overgrazed steep hillsides by heavy rain. (Minnesota, U.S.A. Photo courtesy of USDA Soil Conservation Service)

FIGURE 13. - Sediment deposited at the base of a field on which the crop has been planted up and down the slope in rows. (Illinois, U.S.A. Photo courtesy of USDA Soil Conservation Service)

The end result of uncontrolled water erosion is the loss of soil and consequently destruction of its productive capacity. The visible results on the ground take different forms, depending on local conditions. A common feature is the formation of rills and gullies, which have already been mentioned. Another common feature is the loss of a thin layer of soil over a wide area, usually classified as "sheet" erosion. This classification can be confusing, because it tends to conjure up the possibility of the removal of a uniform thin sheet of soil by a uniform thin sheet of water moving downhill. The term sheet erosion could also be confused with the deposition of a thin sheet of sediment. If the erosion observed can be identified as the removal of a thin layer of soil over a wide area, it is most likely to be caused by rain splash and surface run-off in the manner already described. (5)

Landslides can be initiated by intense rainstorms in mountain areas. For example, in the Uluguru mountains in Tanzania in 1970 a storm of more than 100 mm of rainfall in three hours resulted in more than 1000 landslides over an area of 75 square kilometers. As the rain continued the slides developed into mud flows which joined the water flow at the base of the slope. This sediment was deposited over a wide area of land beyond (9). (Figure 14.)

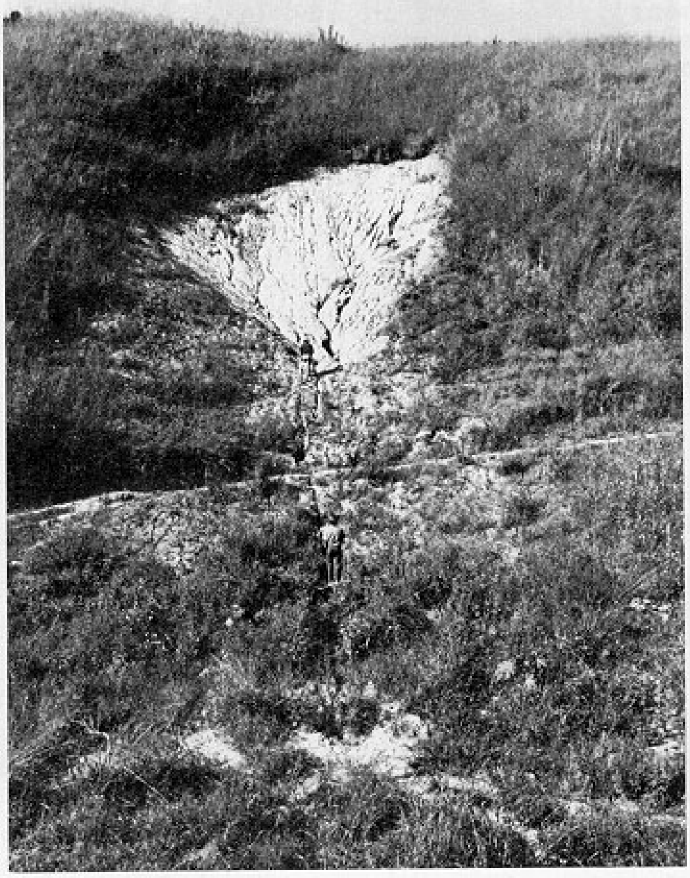

FIGURE 14. - Example of a small landslide and mudflow. (Tanzania (9): Photo by A. Rapp, courtesy of Dept. of Physical Geography, University of Upssala, Sweden.)

The term slumping is often used to describe the collapse of steep gully sides, and the collapse of river banks and coastlines due to undercutting.

3.2 SOIL EROSION BY WIND

Wind erosion can be a problem in all dry and semi-arid areas, and also in areas of seasonal rainfall. Unlike water, which needs a slope to enable it to flow and move soil, wind can remove soil from flat land just as well as from sloping land; it can also transport the particles through the atmosphere and deposit them up to thousands of miles from the original location. The conditions which allow wind erosion to take place are dry loose soil with little or no vegetative cover, a relatively smooth surface, and a wind of sufficient velocity.

Even an apparently smooth surface contains soil particles of different size, and of resistance to the force of the wind. The resistance is known as the boundary friction, which needs a given force of wind to overcome it, but once overcome the body will continue to move. This movement then takes place in three different ways, again according to the size of the particles.

Soil grains within the range of 0.05 to 0.5 mm in diameter move in saltation, which is a bouncing action over the surface of the ground. Particles which are too heavy to be lifted by the wind in the range of 0.5 to 2 mm in diameter - creep or roll along the surface, mainly by the impact of other bodies in saltation rather than by the direct force of the wind. The smaller, very light particles are also bounced up by the impact of grains in saltation, and are then lifted by eddy currents and carried away in suspension by the main airstream to form duststorms. These duststorms usually contain the most fertile fractions of the soil. (Figure 15.)

The coarser, less fertile soil particles pile up against obstacles such as fences, roads or buildings. These coarser fractions also cause abrasion - i.e. they break down clods into smaller erodible sizes; they damage growing vegetation while the wind removes residues, leaving more soil vulnerable to erosion. Thus, the whole erosion process is accelerated. (Figure 16.)

Although the angle of slope is not of major significance in relation to the danger of wind erosion, the length of a field or open ground is of the greatest importance. By the process of saltation increasing numbers of particles are set in motion in the direction of the wind. Thus, the amount of soil moved increases with distance until the wind can carry it no farther, where it settles out or piles up in drifts or dunes.

In order to control wind erosion, it is necessary to reverse one or more of the conditions which favour it. Only dry soil blows, therefore it appears that the obvious solution is to keep it moist. However, this can only be done in a dry area if irrigation water is available. A good cover of vegetation will break the force of the wind and prevent it reaching the soil, but this also requires moisture to enable the vegetation to grow. The only line of defense left in a dry area is to roughen the surface of the ground and reduce the

FIGURE 15. - Example of approaching duststorm. (Colarado, U.S.A. Photo courtesy of USDA Soil Conservation Service)

FIGURE 16. - Result of wind erosion. The borrow pit has been completely filled, soil has drifted onto the road and against the fence, destroying it in the process. (Idaho, U.S.A. Photo courtesy of USDA Soil Conservation Service)

velocity of the wind. This practice works well, because it takes advantage of the phenomenon of zero wind velocity which occurs near the surface of the ground, as explained below.

Wind initiates the movement of soil particles from the surface of the ground by turbulence, which arises from a change in wind velocity in relation to height above the surface, the thickness of which varies according to the roughness of the ground. In other words, the greater the average height of the roughness, the greater the height of zero velocity. This roughness might consist of impediments such as stones, vegetation, vegetative residues or clods. The smaller, erodible particles in between are in the area of zero velocity and thus remain undisturbed. This is why it is good conservation practice to leave crop residues on the field or to leave it in a cloddy condition if it should be necessary to cultivate it in a dry area.

3.3 SOIL DEGRADATION

In the terminology of soil genesis degradation refers to the changing of a given soil type to one that is more highly leached. For example, the formation of a Luvisol from a Cambisol (in the FAO/Unesco World Soil Group Classification). Over the years, however, this term appears to have become generally accepted in the literature to include a decrease in soil fertility. Soil erosion refers to the removal, transportation and net loss of soil. This certainly involves the loss of soil fertility as well. Other forms of soil movement can be classified as erosion or part of the erosion process, such as the breaking down of soil structure and the sealing of the surface, or the washing down of clays and colloids to a lower horizon, or the leaching of soluble plant nutrients by rainfall and run-off.

FIGURE 17. - Soil ruined by the accumulation of salts harmful to plants in the upper layers and on its surface. (FAO photo.)

Salinization and alkalization are some of the most widespread and serious forms of degradation occurring in irrigated areas of high temperature and low rainfall - the concentration of salts toxic to crops in the upper layers and on the surface of the soil due to evaporation. Many millions of acres of once productive land have been ruined for further crop production in this way. (Figure 17.)

Soil degradation can result from other unsuitable cultural practices and mismanagement, both with and without actual removal or transportation of soil - for example, continuous cropping and failure to apply adequate amounts of fertilizers or manures, loss of soil moisture, infestation with harmful bacteria or fungi, waterlogging, sedimentation, acidity and a host of other undesirable results of soil and water mismanagement. It would seem logical therefore that the term soil degradation is being used more generally in the literature to include the result of any process - physical, chemical or biological, which leads to a reduction in the quantitative and/or qualitative productive capacity of the soil.

4. THE PROBLEM OF SHIFTING CULTIVATION

4.1 WHAT IS SHIFTING CULTIVATION?

The term shifting cultivation is generally used to describe a traditional system of organized agriculture which relies on natural fallows for the maintenance of soil fertility. There are three main forms of the system, all of which have been used throughout the world during the evolution of agriculture. Oldfield (10) found evidence of initial and secondary forest clearance in Britain dated approximately 4 960 and 4 500 years ago using stone axes.

In the simplest form of the system farmers clear, burn the cleared vegetation and cultivate plots of land in virgin forest, bush or grassland until the yields of the crops fall below subsistence level. The decrease in yields is usually due to one or more of the following causes - depletion of plant nutrients, heavy infestation by weeds, pests and plant diseases, and soil erosion. At this point the farmers abandon the land to natural fallow and move to a new site, taking their dwellings with them, or building new ones at the new location. When the original area is considered to have recovered fertility, the cultivators return to repeat the process, until once again the land is apparently exhausted. The period of fallow varies according to the climate and inherent fertility of the land, from around two or three years in tropical rain forest, up to 20 or even 30 years in semi-arid areas. (Figures 18 and 19.)

FIGURE 18. - Shifting cultivation in Zambia - known as "chitimene". Early stages of fallow. (Photo Ministry of Overseas Development, Land Resources Division, U.K.)

FIGURE 19. - "Chitimene" in Zambia. Later stage of fallow. (Photo Ministry of Overseas Development, Land Resources Division, U.K.)

In another form of shifting cultivation, which is a stage nearer to permanent settlement, the dwellings remain on the original site but the cultivators clear new land within daily travelling distance, or, if the new area is too far for this purpose, they erect temporary shelters for use during peak labour periods.

Finally, the most settled of these systems comprises basically a group of permanent homesteads surrounded by permanent fields rotated with natural fallow. This is not shifting cultivation in the true sense, but has been generally accepted as such in some countries. It employs the same basic principle of natural fallow to restore soil fertility, and the area under fallow is not used for any other productive purposes, except that in some communities animals are allowed to graze the stubble.

4.2 THE NEED FOR INTERNATIONAL TERMINOLOGY

The exact terminology to use for the various forms of shifting cultivation has caused some confusion within recent years because of the various interpretations prevalent in different countries. This problem came to light when FAO received replies to a questionnaire requesting detailed information on shifting cultivation from developing countries in 1973. Consequently this problem was discussed at the FAO/SIDA/ARCN Regional Seminar on Shifting Cultivation and Soil Conservation in Africa in July 1973 with a view to establishing common terminology for international discussion (11). A working group to examine this question was appointed and their main recommendations were as follows.

All forms of land cultivation should be divided into two main groups - continuous and non-continuous systems of cultivation.

Continuous systems of cultivation are those in which there are some definite and continuous forms of land management or crop rotation where the natural fallow is replaced by a planted fallow crop, a planted tree crop or managed grassland.

Non-continuous systems of cultivation comprise shifting cultivation and natural fallow cultivation. Shifting systems are those in which the dwellings are moved to the new area to be cultivated every time a move takes place. Natural fallow systems are those in which the dwellings normally remain where they are but a new area of cultivation is established elsewhere.

The natural fallow systems should again be subdivided according to the nature of the vegetation comprising the fallow into - forest, thicket, savannah and grassland, defined as follows:

Forest	-	woody vegetation with closed canopy in which large trees are ecologically dominant;
Thicket	-	dense woody vegetation without closed canopies, in which low growing trees are ecologically dominant;
Savannah	-	a mixture of fire-resistant trees and grasses in which tall grasses are ecologically dominant;
Grassland	-	grasses without woody vegetation, in which short grasses are ecologically dominant.

It was also suggested that a fallow period which becomes shorter than it should be for the type of vegetation comprising the fallow, should be defined as accelerated.

In order to relate the period of cropping to the period of fallow it was suggested that this should be indicated by the C/F ratio, where C is the length of the cropping period, and F is the length of the fallow period in years respectively. For example, a given natural fallow system could be described as non-continuous, accelerated forest fallow 2/5.

4.3 POPULATION INCREASE AND DECREASING YIELDS

A common feature of all these non-continuous systems of cultivation is low intensity of cropping and thus they are suitable only in areas of low population and an abundance of land. When the population increases beyond the critical level which the system can support, the additional output required is obtained by reducing the length of the fallow in order to increase the intensity of cropping (11). At this point the natural cycle is broken, and rapid soil degradation sets in. Yields become progressively lower per unit area of cultivated land and unless remedial measures are taken, the community may suffer severe food shortage and possible starvation.

According to the history of the evolution of agriculture in developed countries in the temperate zones it would appear that the permanently settled form of natural fallow cultivation should offer the best prospects for increasing production because of the better infrastructure associated with this type of settlement. This kind of settlement was prevalent up to the end of the seventeenth century in Europe and Britain in the form of the two-field and three-field systems. The breakthrough required to substantially step up production came with the introduction of continuous cultivation as defined in 4.2, that is, replacement of land rotation by crop rotation or fallow crops, which were themselves economic, in conjunction with heavy dressings of manure, the use of more powerful farm machinery and finally chemical fertilizers. This trend has been followed, and indeed encouraged, in the developing countries as well.

Whereas in Europe soil fertility was maintained and even increased as production increased, in the Tropics the results have not been so successful. Food production is not keeping pace with the increasing population, and the gap is getting wider. The reasons for this are complex, but there are three which are significant. The first is that the output from non-continuous cultivation is in any case low, and it is still practised on 36 million square kilometres of land, which represents about 30% of the world's exploitable soils.

The second reason arises from the differences in climate and soils. As already indicated in Chapter 2, tropical soils are more susceptible to erosion by water and wind than soils in temperate areas. Certain cultivation practices, such as ploughing, and even ridging up and down the slope, leaving the soil bare to rain and wind, and intensive tillage may do no great harm in some temperate areas, but lead to certain disaster in high rainfall and semi-arid areas in the Tropics.

The third reason is connected with the second, and it is due to a paradoxical situation in which efforts to increase production must lead to more intensive cultivation, and the reduction or eventual elimination of the built-in conservation measure - the natural fallow. Without remedial measures, this leads to more soil erosion, degradation and reduced yields.

4.4 PROPSECTS FOR IMPROVEMENT

Much can be done to increase production by applying inputs such as better seed, high yielding varieties, fertilizers, manures, crop rotations, mixed farming (livestock and crops), and soil conservation measures. But, maintaining an adequate supply of plant nutrients when the natural fallow cycle is reduced or eliminated is the major problem.

Chemical fertilizers can supply needed plant nutrients. However in the humid Tropics the dominant kaolinitic clay minerals have low absorption capacity and chemical fertilizers are fully effective only in combination with humus. This requires the use of organic manure on a large scale to maintain soil fertility (12). In many of the drier areas in the developing countries, there is very little animal manure available for this purpose because most of it has to be used for fuel and as binding material for the construction of dwellings. Where livestock are kept in large numbers there may already be a soil erosion problem due to uncontrolled grazing, or overstocking, although controlled grazing and regulation of grazing intensity could solve this problem. But where there are very few animals another solution has to be found. Composting crop residues or stubbles does not seem to offer much prospect because these have to be consumed by the animals. More promising lines of approach are the growing of fodder crops which can be cut or grazed, particularly leguminous crops which fix nitrogen from the air, and intercropping with legumes. Nitrogen fixation by cereal crops which is now receiving urgent attention by research workers, offers another possibility.

The results of research in Nigeria confirm that much higher yields of crops can be obtained by combining organic manures with mineral fertilizers than by using chemical fertilizers alone, and that this combination seems to be the best way of continuously maintaining fertility in tropical soils. (Agboola, Obigbesan, Fayemi, 1974 (12).) On this assumption, the results of investigations on the maximizing of the efficiency of fertilizer nitrogen offer interesting possibilities.

The efficiency of fertilizer nitrogen might be increased with controlled release fertilizers, including the use of coated granules, and compounds of limited water solubility blended with conventional nitrogen fertilizers. Formulation of ammoniacal fertilizers with nitrification inhibitors could also increase fertilizer nitrogen efficiency. (Parr, 1974 (13).)

In forest reserves there appear to be prospects for extending rotation, or mixed cropping with farm crops and economic trees in an integrated resource management plan. A form of this idea, known as agri-silviculture, has been in operation on a limited scale in Tanzania for many years. There, cultivators are granted a licence to enter the forest reserve, clear an agreed area of land, and plant food and cash crops for an agreed number of years, at the end of which they must replant the cropped area to tree species specified and supplied by the Forestry Department. They must then maintain the newly planted areas of trees under the supervision of the Department. The limitation of the system is that the cultivators have no real long term security of tenure.

In Nigeria St. Barbe Baker in 1928 (15) reported on a system of agri-silviculture in tall forest at Sapoba in the Mid-Western State, in which crops such as maize, yams, groundnuts, okra, beans and peppers were planted between rows of teak. A bonus was given to farmers who succeeded in establishing not less than 500 trees per acre. From this beginning systems of agri-silviculture have spread throughout Nigeria. (Adetogun, 1971 (16).)

In 1968 King (14) collected information on agri-silviculture practices (taungya) from 72 Government Forest Departments throughout the world.

He concludes from his survey that there are very few insurmountable biological problems in agri-silviculture. He points out that a great deal of social upset has already been caused by the abandonment of shifting cultivation, and suggests that agri-silviculture offers some help in the solution of tropical land use problems and the development of a stronger rural and national economy.

PART II

SOIL CONSERVATION

5. ACTION FOR SOIL CONSERVATION AT NATIONAL LEVEL

5.1 THE MEANING OF SOIL CONSERVATION

The meaning of soil erosion and the factors which cause it are discussed in Part I of this Bulletin. The results in a society dependent on agriculture in terms of decreasing crop yields, food supplies and standards of living affect every man, woman and child in the rural area eroded. The repercussions are felt in the urban areas and in the country as a whole due not only to food shortages but to economic stagnation and social unrest as well. Thus, the loss of soil fertility and potential production through erosion and soil degradation is a national problem, the solution of which concerns not only the farmers who produce the food, but the urban dwellers who need to consume it, and the Government which has control over land use, agrarian, land tenure and taxation policies. The solution must be found through national programmes of soil conservation, which in this context means the application of all measures necessary to conserve the whole complex of land and water resources.

5.2 OBJECTIVES OF A NATIONAL SOIL CONSERVATION PROGRAMME

The broad objectives of a national soil conservation programme should be to increase food production and the standard of living of the people by applying soil and water conservation policies and measures to the best advantage. It would therefore be prudent to arrest soil erosion on settled land moderately affected by erosion first, by building up soil fertility and production there before embarking on expensive reclamation type measures on lands seriously denuded or abandoned as apparently beyond repair. However, it might be necessary to reclaim seriously denuded and sub-marginal lands as soon as the necessary finance could be found if population pressure demanded it. Such national soil conservation programmes involve the introduction of technical innovations and social change and to be successful need the understanding and support of the population as a whole. Therefore the first priority is to awaken the people to the problem and the measures available to solve it, by education of all levels of the community. This provides the motivation for action by farmers, extension workers and Government officials. But the farmers who actually work on the land, many of them mindful of the problems, need more information on how to conserve the soil, and need to be convinced that by so doing they will increase their income and general welfare.

During this century there has in fact been an awakening to soil erosion and conservation problems throughout the world, stimulated very largely by the publicity of the soil conservation movement in the U.S.A. Although there is now a general awareness of the problem, it would appear that this is not being translated into remedial action at the farm level. There are socio-economic problems to be faced, but these need not be used as a scapegoat for less than success in the transmittal of technical knowledge and the provision of practical technical assistance to farmers. In many countries specialized soil conservation services are for all practical purposes non-existent. In other countries there may be a multiplicity of extension workers whose activities are not being co-ordinated towards the same objective, due to several government departments and ministries dealing with allied land and water use activities. A national programme of soil conservation and increased production needs a multi-disciplinary approach, and the best chance of success lies in the co-ordination of all the disciplines necessary under one department, or at least under one ministry. If this is not possible an overall Council must be established to co-ordinate policies and priorities.

5.3 SOIL CONSERVATION SERVICES

An organization to implement soil conservation policies, set standards and to carry out activities at national, state, district and farm level is necessary. This is true irrespective of whether these activities are supervised, financed and co-ordinated by a government department or ministry. Such services may range from a small group of specialized staff with equipment and machinery for earth moving, dam building and mechanical protection works to a comprehensive organization like the Soil Conservation Service of the United States Department of Agriculture.

It will be apparent from Chapters 2 and 3 that the study of soil erosion and its causes and the establishment of principles for remedial measures involves the employment of staff trained in all the agricultural and engineering sciences normally taught in agricultural departments of universities and colleges. It is only within recent years that a few specialized institutions have been established which are truly multi-disciplinary and deal with the subject matter of Chapters 2 and 3 in courses of agricultural engineering.

In the developing countries in the Tropics and elsewhere soil conservation is an essential part of good farming practice. It would appear logical therefore that agricultural extension workers destined to work in the Tropics, whether derived from international, bilateral or local national sources, should be trained in the subject matter of soil conservation. Preferably national departments or ministries of agriculture would be staffed with personnel, both at headquarters and in the field, who had this kind of training and experience.

There is a need for establishing a specialized soil conservation service with initially a small nucleus of extension staff fully trained in Tropical agriculture and soil conservation at an institution providing such integrated training. This nucleus should be provided with the necessary teaching equipment, survey equipment and machinery to assist farmers to implement soil conservation programmes which they cannot carry out themselves, due to lack of knowledge and resources. This embryo soil conservation service would concentrate on areas most in need of help, and at the same time train field staff. The next step would be to establish an organization and services on an area basis throughout the country. Once this country wide coverage had been achieved, and soil conservation measures applied, the effectiveness of these measures should be constantly evaluated and revised to incorporate improved methods.

5.4 SOIL SURVEYS

Soil surveys are necessary to define and evaluate soil types, slope, existing land use or natural cover, susceptibility to erosion, and the degree of erosion which has already taken place, as a basis for determining the suitability of the land for various uses under given conditions of management. The starting point is a field soil survey which locates and identifies soils by mapping units. A land capability classification is then prepared and related to the soil mapping units. The best known of these systems is the one developed by the Soil Conservation Service of the U.S. Department of Agriculture (17). The classification is divided into: capability units; capability sub-classes; capability classes. The capability units group soils that have about the same influence on crop production, and respond in about the same way to the management requirements of common crops, including pasture plants. The sub-classes group capability units having similar limitations and hazards, e.g. erosion hazard, wetness, root zone and climate limitations. The capability classes describe progressively, in eight stages, the degree of risk to soil damage and limitations in its use.

Table 4 is a simplified version of the eight land capability classes and the information available under each class according to erosion risk and suitability of the land.

TABLE 4

<u>Land Capability Classes</u>

Class	Suitable for Cultivation
1	No risk, only good management necessary
11	Some risk, moderate conservation practices necessary
111	Considerable risk, intensive conservation practices necessary
1V	Great risk, best for perennial vegetation and infrequent cultivation
	Suitable for pasture, hay, woodland and wildlife
V	No restriction
V1	Moderate restriction in use required
V11	Severe restrictions in use required
V111	Suitable only for wildlife and recreation

Attempts to adapt the USDA system to conditions in developing countries, particularly in areas of shifting cultivation, have met with some difficulty, because the system assumes a high level of management not yet generally practised in these areas. A new system of land suitability classification is being developed, tailored to the special needs of developing countries. (FAO, 1972 (18) and Beek and Bennema, 1972 (19).) This proposed system integrates social and economic factors with the technical suitability classification. In other words it recognizes that intensified land use requires inputs, some of which can be supplied by the farmers themselves. Other major inputs such as the introduction of irrigation, land shaping, terracing or land clearing are usually beyond the capacity of the farmers and have to be provided and financed from other sources. Thus for purposes of economic appraisal, the potential land use which could be achieved by injecting major capital inputs can be included in the overall evaluation.

A prerequisite for land suitability classification is reliable data on crop performance under existing conditions, projections of performance under improved conditions, and data on the physical environment, particularly climate and hydrology. The lack of adequate data on these aspects, particularly in the areas under shifting cultivation, is a problem which again has to be solved by the provision of inputs such as establishment or improvement of research and recording facilities, and for the results to be meaningful they must be based on many years of observation.

However, these limitations should not preclude the immediate undertaking of reconnaissance surveys based on available data and visual inspection, so as to pinpoint the most obvious problem areas for attention. Classes I to VIII of the USDA land use capability system can be used as a basis for such surveys, but great care has to be taken in its interpretation according to prevailing local conditions. All the factors involved must be appraised very carefully and on no less than a complete watershed or catchment basis. Possible new or untried remedial measures should then be tested on research stations and demonstration areas, with the co-operation of local farmers, who, more often than not, may have useful suggestions to offer based on their long experience of the area concerned. From these small beginnings and the continued collection and interpretation of data it will be possible to develop suitable land use and management classification maps for each ecological zone. Lines of research needed to achieve this end are discussed in Section 5.5.

5.5 RESEARCH

Research in the science and practice of soil and water conservation is apparently still lagging behind other agricultural research such as the use of chemical fertilizers, weed, insect and disease killers and high yielding crop varieties. Maximum benefits cannot be derived from high yielding varieties, and even normal varieties, on a sustained basis without first providing and maintaining a high soil fertility level. The continued application of chemical fertilizers can hardly be economic if the soil and the nutrients are being lost through erosion. It would appear therefore that research programmes should be concentrated on soil conservation and fertility in order to develop criteria on which sound recommendations can be made, especially with regard to shifting cultivation. This aspect was discussed in detail at the recent FAO/SIDA/ARCN Regional Seminar on Shifting Cultivation and Soil Conservation in Africa in July 1973. The detailed recommendations of the Seminar are contained in its Report - FAO/SIDA/TF 109 published in Rome in 1974 (11). Some important aspects of these recommendations are stressed herein.

There is an urgent need to review the present state of knowledge on shifting cultivation and to collate and analyse data systematically. More information is needed on climate, soils and ecological zones.

For example, under climate, records of mean monthly and annual precipitation are not sufficient; intensity and duration of storms must be included. Records must also be kept in sufficient detail and over long enough periods of time so that statistical evaluations of rainfall probabilities can be made. Records are also required of temperature (including soil temperature); relative humidity and evapotranspiration; radiation; winds; and micro-climates, including the effects of vegetation on climate.

National organizations must be equipped to prepare soil maps. The description of the soil profiles should follow the FAO guidelines on soil description to ensure uniformity, and the soils should be accurately correlated. When describing soil series it is important to define the range of characteristics of each established series. Information should be included on soil pH, colour, texture, drainage, organic matter content and parent material. The knowledge which the local farmers already have about their soils should not be ignored.

Different ecological zones should be related to different cropping practices and response patterns - e.g. rain forest zone of high rainfall and acid soils; semi-deciduous forest zone of more moderate rainfall and less acid soils, etc.

More detailed information is required on present shifting cultivation practices as follows:

- population densities in relation to the ratio of land cultivated to fallow; length of cropping period;
- criteria for selection of land for clearing; local knowledge of soils and plant indicators;
- agronomic information on methods of clearing and planting; crop sequences and mixed cropping; times of planting, population densities, harvesting methods and yields;
- social factors affecting land use and agronomic methods;
- economic factors - extent to which crops are sold; prices; transport and markets; land ownership and land tenure policies and customs.

Research is required on the changes which take place in soil fertility, structure, moisture regime, temperature etc. as a result of shifting cultivation practices. For example, what happens to the soil as a result of clearing and burning and clearing without burning? What happens during the cropping period and the fallow period? What happens when alternative systems of cultivation are introduced and what are the effects of different tillage practices, such as deep ploughing or minimum tillage?

In the search for alternative systems of cultivation which are more productive and at the same time soil conserving, more attention should be paid to the application of inexpensive and simple agronomic practices as the first line of defence, and to ascertain at what point more expensive mechanical protection works are necessary. More information is needed on the effect of the different rooting systems of annual, biennial and perennial plants, on the effect of grass fallows, the accumulation of organic material in the savannah zones, and on mixed cropping as compared to single cropping.

In addition, and given the importance of crop residues in erosion control, studies should be made of the effects of burning of residues versus removal by other means such as ants and how best to maintain residues on the surface. The effects of surface mulches or crop residues on yields should also be studied.

5.6 LEGISLATION

Soil conservation programmes, whether nationwide in scope or confined to specific problem areas, need the enactment of appropriate legislation to enable administrative action to take place. The proportion of national resources to be allocated to the implementation of programmes depends on priorities selected from among apparently conflicting interests, such as short term economic goals and long term protection of the soil. The selection of priorities becomes less difficult when the problems and the objectives of the programme are clearly defined and understood.

Economists and legislators have sometimes been somewhat wary of the term soil conservation because it appears to imply immediate large scale investments, increased costs of production and deferred and uncertain returns. On the contrary the application of soil conservation practices as explained in Sections 5.1 and 5.2 leads to both immediate and sustained long term improvement in yields, while failure to do so leads to progressively decreasing yields. Therefore, the objective of soil conservation is synonymous with the goals of social and economic development.

Sometimes legislation is introduced which enables the responsible minister to make rules for the application of specified soil conservation measures in problem areas. Such legislation recognizes that a problem exists, but may not always ensure that the rules can be translated into action on the ground. It is the farmer himself who has to carry out the provisions of the rules, which he cannot do if he lacks the necessary knowledge, equipment and finance.

If it is accepted that soil erosion is a national social and economic problem, and its solution lies in the application of all measures necessary for the controlled development and conservation of land and water resources, then a comprehensive resources law would appear to be the final objective. The priority would seem to be to establish the machinery necessary for education, extension, survey, research, the provision of facilities and technical assistance as the first step in the legislative programme. That a comprehensive resources law has not yet been enacted in many cases, or is not regarded as necessary, is illustrated by the following summary of the varying state of soil conservation legislation in developing countries. (21)

In the Far East Ministers are frequently given authority to control erosion even without particular soil conservation legislation. Forestry and grazing laws are found in most countries with soil conservation laws. Other countries have laws to control only individual problems, such as stream bank erosion.

In Latin America forestry laws are almost universal, reflecting the regional importance of forest lands, even for grazing and crop production. Some other countries have regulations to control clearing, burning or other particular activities.

In Africa south of the Sahara forest legislation is widespread, but laws aimed at farm cropland problems are less frequently encountered. In many cases laws have not been introduced at all, or have not yet been adapted to specific problems such as shifting cultivation. Zambia however has a single Statute under which all natural resources may be governed.

In the Middle East and North Africa grazing and forest laws are common, but general conservation legislation is relatively rare.

In North America the far reaching and comprehensive soil conservation legislation of the United States has evolved by the progressive integration of many legislative acts as problems and solutions have become more clearly defined. The first official action was educational, when in 1928 the USDA published a bulletin under the title of "Soil Erosion - A National Menace". This was followed in the same year by Congress providing funds under the Agricultural Appropriations Bill to establish experiment stations to measure the rate of soil and water losses, to survey the extent of erosion damage, to locate the worst affected areas, and to work out remedial measures. A Soil Erosion Service was established in 1933 in the Department of the Interior, and this was re-named the Soil Conservation Service and transferred to the Department of Agriculture in 1953 (Public Law 74 - 46). The purpose of the law was defined "to provide permanently for the control and prevention of soil erosion and thereby to preserve natural resources, control floods, prevent impairment of reservoirs and maintain navigability of rivers and harbours, protect public health, public lands and relieve unemployment, and the Secretary of Agriculture, from now on, shall co-ordinate and direct all activities with relation to soil erosion".

The next act of particular importance was the Soil Conservation District Law of 1936 to initiate local self-help programmes at District level within the State. Today there are nearly 3000 locally governed soil conservation districts covering 600 million hectares of land and over 90 percent of all farms.

Official recognition of the role of soil surveys in relation to conservation came in 1952 when all Federal soil survey activities were transferred to the Soil Conservation Service.

Many other laws deal with specific aspects of the soil conservation effort, but in 1962 the all-embracing Food and Agriculture Act was passed which authorizes the Secretary of Agriculture to provide for a complete soil conservation programme based on hydrological units.

The evolution of soil conservation legislation in the United States is quoted because it has been based on the recognition that a problem existed. Then solutions were tried, evaluated and refined according to the economic and social needs of that country. The key to the success of the soil conservation movement in the United States is local involvement of the people, achieved by state enabling legislation. In this way farmers could organize local soil conservation districts. Thus these districts have been organized by popular demand and are governed by locally elected representatives.

In the developing countries the basic problems of soil erosion are much the same, but the remedial measures may have to be adapted to local conditions and availability of scarce resources. The approach to the problem is universally applicable, and many countries are now taking advantage of the United States experience.

6. SOIL CONSERVATION PRACTICES

6.1 GENERAL PRINCIPLES

6.1.1 Good Farming

Good farming practice, rational land use and efficient management of soil, crops and livestock result in sustained high yields, which provide the best basis for ensuring adequate returns to the farmer and the country as a whole. Fortunately sustained high yields usually coincide with minimum soil erosion.

There is ample experimental evidence to support the relationship between high levels of production and minimum soil erosion. The result of an experiment on maize in central Africa given in Table 5 (5) is a good example, especially as maize was at one time considered to be a soil-depleting and erosion-inducing crop. As mentioned in Chapter 2 the extent to which a crop permits erosion is due more to the way it is grown than to the nature of the crop itself.

TABLE 5

Run-off and soil loss under medium and high levels of maize production. (After Hudson (5))

	Plot A medium level of production	Plot B high level of production
Plant population	2500 plants/ha	3700 plants/ha
Fertilizer application	N 20 kg/ha P_2O_5 50 kg/ha	N 100 kg/ha P_2O_5 80 kg/ha
Crop residues	Removed	Ploughed in
Crop yield	5 ton/ha	10 ton/ha
Run-off Soil loss	250 mm 12.3 ton/ha	20 mm 0.7 ton/ha
Season	1954/55	1954/55
Rainfall	1130 mm	1130 mm

Of course the nature of the crop and its habit of growth is an important factor as well. For example leafy spreading and low growing crops such as legumes and prostrate type grasses generally protect the soil from rain splash better than single stemmed erect crops. But, the point being made is that many of the disadvantages of the latter can be eliminated by growing them in a different way. It will be noted from Table 5 that the run-off and soil loss on plot B with the high level of production is very much less than from plot A with a lower level of production. Furthermore, after 10 years the soil of plot B was in better condition from all points of view - structure, moisture and nutrient status - than plot A.

Apart from the high yield and low erosion rate resulting from this high level production, the water balance was improved, because ample additional moisture became available for the high yielding crop due to the marked reduction in run-off. In addition soil organic matter was maintained by producing the greater quantity of crop residues.

It follows that high plant populations need high fertility and adequate moisture to obtain maximum yields. The plant population which coincides with maximum yield at a given fertility status is known as the optimum population. Similarly, progressive increases of fertilizer applications will increase yields up to a certain point, beyond which further applications will not result in any further useful increase in yield - that point is known as the optimum fertilizer application. The combination of optimum plant population and fertilizer application is a very potent tool in soil conservation and usually coincides with maximum profit. A very interesting example of this combination as a soil conservation tool on sloping land is illustrated in the graph, Figure 20.

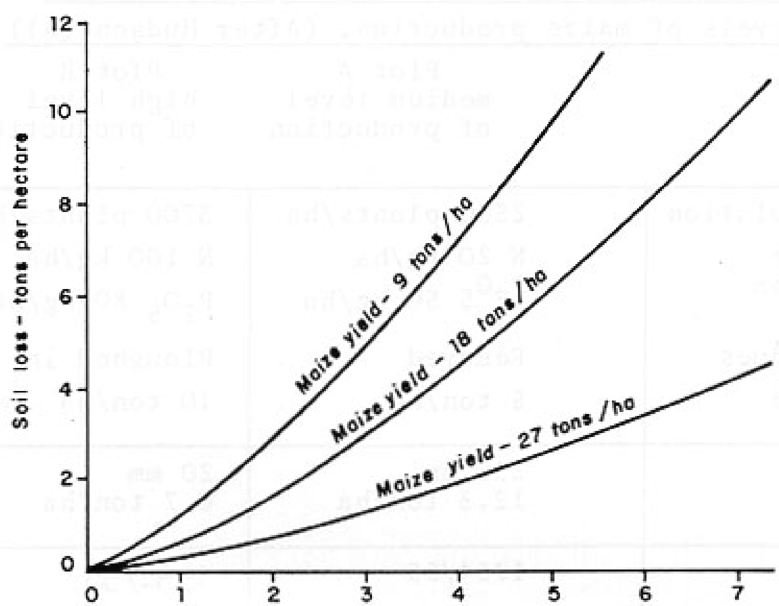

FIGURE 20. - Relationship of three levels of production of maize to soil loss and slope. (After Hudson (5))

This refers to maize produced at three levels of production, 9, 18, and 27 tons/ha plotted against slope and soil loss. The soil loss is least at a yield of 27 tons/ha, and most at the lowest yield of 9 tons/ha, for all slopes.

In the case of grazing land, maximum production and profit from animal products such as meat, wool or milk is obtained when the stocking rate is correct for the carrying capacity of the pasture. Once again good livestock farming happens to be a good soil conservation practice as well.

6.1.2 The Role of Agronomy and Tillage

When the soil is cultivated and left bare to the action of water and wind the danger of soil erosion is very great as explained in Chapter 2. It follows that the best soil conservation measure is to keep it 100 per cent covered and to disturb it as little as possible. The nearest approach to the perfect case is natural forest and well managed pasture. For arable farming however the land must be planted to crops and this usually requires cultivation but even so the aim must be to keep the land covered as densely as possible during critical erosion periods. There are various ways of doing this either singly or in combination. One way is to grow the crop itself at the highest possible plant population as in the example given for maize in 6.1.1 above. Another way is to grow special seasonal cover crops such as legumes, or to grow crops in rotation. The soil can also be kept covered by leaving the stubbles and residues on the surface of the land. If they are incorporated with soil by tillage the surface of the soil must be left rough and cloddy during critical erosion periods. In seasonal rainfall areas, the land should normally be left in this cloddy condition until the onset of the first showers of rain, when the seed bed can be prepared, (Figures 21 and 22). This is the most dangerous time from the soil erosion point of view because the surface of the land is smooth and bare. If there is little or no slope to the land and the soil has good structure and enough organic matter rainfall erosion may be negligible, but if the slope is appreciable other protective measures may be necessary. In areas with long dry seasons the hazard of wind erosion can also be reduced by leaving crop residues on the surface of the soil or by leaving it in a rough cloddy condition, (Figures 21 and 22.)

On sloping land in areas of high intensity rainfall it is nearly always necessary to introduce additional erosion control practices as well as employing the principles mentioned above. Some of these measures are still basically agronomic or cultural while others are purely mechanical. The aim of the additional practices is to reduce the velocity of run-off and to encourage the water to infiltrate into the soil and to dispose of the surplus water safely. The complexity of the measures required depends largely on erodibility of the soil, degree of slope, crops grown, how they are grown and the amount and intensity of rainfall. Assuming that the farming system is basically soil conserving, simple and inexpensive additional agronomic and cultural practices will go a long way towards controlling soil erosion and maintaining soil fertility.

FIGURE 21. - Rough cloddy condition produced by a disc plough helps to control erosion by both rainfall and wind. (Tanzania: Photo by I. Constantinesco)

FIGURE 22. - Rough cloddy condition produced by a chisel type plough in hard dry soil subject to wind erosion. (Tanzania: Photo by I. Constantinesco)

The first and most fundamental step to take is to carry out all tillage operations on the contour, or at least across the slope instead of up and down it. Other supporting agronomic practices could include strip cropping, sod-based and tree-based rotations, live barrier hedges and trash bunds singly or in combination. Tillage operations to help intercept run-off and encourage infiltration of water into the soil could be subsoiling, ridging and tied ridging.

Should erosion still take place when all these good farming, land use, agronomic and tillage practices have been applied- which is unlikely on moderate slopes - then, and only then should it be necessary to introduce more complex and expensive mechanical protection works such as terraces. On steep slopes cultivated with annual crops terracing will almost certainly be necessary, where conventional tillage methods are used.

6.1.3 Mechanical Protection Works

Mechanical protection works are to supplement good agronomic or cultural practices and should not be viewed as a substitute for them. They are usually permanent structures of earth or masonry, or a combination of both, which have to be constructed either by hand labour or machinery to protect the soil from erosion by water and also to conserve water. These include interception, diversion or storm channels or drains and terraces of various kinds, waterways for drainage and water disposal, gully control structures, and dams. Design and construction of these practices to acceptable standards is essential if they are to be effective and require minimum maintenance.

The main purpose of the diversion type channel is to protect lower lying land from erosion by intercepting run-off flowing down a slope (which would remove soil by scouring) and dispose of it safely into a main drainage channel or waterway. Level terraces intercept and arrest run-off and thus encourage the water to soak into the soil. Graded terraces intercept run-off as well and carry excess water safely to a protected drainage way. In addition, most terrace layouts are designed to reduce the effective length of the slope of the land, thus reducing the hazard of erosion by run-off.

Surplus water from diversion channels or terraces is usually disposed of by surface drainage to main drainage channels or waterways planted with sod forming grasses. Gully control structures usually take the form of small dams constructed of rock, masonry, brush or wood which reduce the velocity of the water flowing down the gully and dissipate its energy. Dams are water conserving and flow control structures which are used to store water for irrigation, for watering livestock or domestic consumption.

With most land which is cultivated on slopes, no matter what soil conservation measures may be applied, all effort in this direction can be ruined by run-off water flowing down the hill or catchment above, entering the cultivated area and scouring out rills or gullies, washing away crops, or breaking down terraces. An interception or diversion channel outside and above the cultivated area is the best remedy in this situation and is in fact absolutely essential. In many cases this may be the only mechanical structure necessary in addition to good agronomic and tillage practices.

It is surprising how often this simple, cheap and effective practice is overlooked.

6.1.4 Planning for Soil Conservation at the Farm Level

A soil conservation plan is a blueprint for measures needed to control erosion. It should be prepared in consultation with, and with the co-operation of the individual or groups of individuals involved in the decision making process, because it is they who will have to implement the plan.

In the developing countries, particularly the large areas of land under shifting cultivation, the majority of the farms are small, scattered or fragmented and under various forms of ownership, tenancy or usufructory rights. Therefore under these conditions it is not practical to prepare conservation plans for each individual farm. Each area which may consist of several farms, or group of such areas under cultivation must be considered as one land management unit for planning purposes. Political and administrative boundaries do not necessarily coincide with catchment boundaries, but they have to be considered in selection of areas for planning in accordance with soil, climate, topography and land use.

As water conservation is inseparable from soil conservation, the ideal unit to consider is one hydrologic unit or catchment. In practice it will most likely be necessary to divide larger catchments into smaller more manageable units.

The planning process should therefore start after a decision has been made as to which catchment or catchments are in need of treatment in order to raise agricultural production. The first step is to systematically collect as much available information as possible about the area - soils, topography, rainfall - amount, distribution and intensity - drainage systems, stream flow, present land use, ecological and social conditions, and so on. The gathering of all this information will take time, money and personnel and this means selecting priorities on information needed within resources available. It should not take too long to find out why soil erosion is taking place, and to try to introduce some of the most obvious remedial measures immediately while more detailed information is being collected. For example - is run-off water from slopes above rushing through cultivated lands? If so can the run-off be diverted and disposed of safely outside the cultivated area? Are the farmers carrying out obvious malpractices such as burning crop residues or cultivating and planting crops in rows up and down the slope? If so steps should be taken for immediate correction. If wind erosion is the problem what are the possibilities of planting wind breaks? Are some of the farmers already successfully using indigenous soil conserving systems of cultivation which could be extended on a wider scale, such as pit systems, mound systems, trash bunds, mixed cropping, grass or bush fallows, ladder terracing or bench terracing? These and many other questions and possible answers should come to mind after the initial field reconnaissance survey by the planner. The success of any plan will depend on the confidence which the farmers place on the advice given to them by soil conservationists and/or extension workers. This confidence can only be built up by promoting continuous dialogue and discussion among themselves and with the extension workers, and by practical demonstration. The most convincing demonstrations are those which are carried out on the farmers' lands using the resources which they have. Demonstrations on experimental farms and research stations are seldom so convincing because the farmers may imagine, sometimes correctly, that the methods and systems demonstrated are beyond their understanding and resources.

After sufficient data has been gathered the plan should be finalized, in consultation with the individual or individuals responsible for implementing the plan. When agreement is reached on the soil conservation practices to be applied, these should be shown on the plan map. Quantities, cost estimates and appropriate designs should be included as part of the plan. A timetable for implementation should also be included. During implementation of the plan careful supervision must be given to the installation of structures. In addition it is essential to keep all parties involved fully informed as to the purposes and results to be expected.

While the plan is being applied to the land the results must be monitored to see if the plan is meeting its objectives.

6.2 COVER CROPS, MIXED CROPPING AND GREEN MANURING

As previously mentioned the best way to control erosion is to keep the land covered. The main advantages of cover crops are - they protect the soil from erosion by both rainfall and wind, they smother weeds, and they can be incorporated in the soil as green manure. Sometimes the cost of establishing and maintaining cover crops may exceed the benefits, but there are many instances where they are used successfully, such as in orchards and plantation crops (Figure 23).

Another common and successful form of cover/mixed cropping is to be found in the coffee areas of East Africa, where coffee and bananas are grown together. The habit of the banana gives shade to the coffee trees and the leaf fall provides a mulch cover to the soil, (Figure 24).

A grass or grass/legume mixture can also be sown together with a grain crop such as maize, wheat or sorghum. By the time the grain is harvested the cover crop will be established and protect the soil from erosion and serve as a green manure crop. Ley farming is a development of this principle, when the grass or grass/legume mixture is used in rotation with the main crop, (see 6.4).

A green manure crop generally refers to one which is grown specifically to improve the soil structure and fertility by ploughing in. It is seldom economic to take up land to grow a green manure crop just for this purpose, but the green manuring properties of crops can certainly be exploited by combining the added advantages of erosion control and nitrogen fixation in a planned rotation.

FIGURE 23. - The use of natural grass cover between the rows of sisal plants. (Tanzania: Photo by I. Constantinesco)

FIGURE 24. - Mixed cropping with coffee and bananas. Note dense mulch cover due to banana leaf fall. (Tanzania: Photo by I. Constantinesco)

TABLE 6.

Erosion control effect of crop residues left on the soil surface compared to ploughing in [1]

Location and soil type	Period	Average rainfall mm	Treatment	Average run-off mm	Average soil loss t/acre
Santa Carolina-Cecil Sandy Loam 8% slope	Growing season 1943-53	561	maize stalks and cover crop ploughed in [2]	35.6	1.2
			maize stalks and cover crop mulch [2]	15.2	0.4
			maize stalks ploughed in [3]	94.0	2.8
Iowa-Marshall Silt Loam 10% slope	Annual 1943, 1945/46 and 1949	807	Residue ploughed in	55.9	8.1
			Residue mulch	53.3	2.5

[1] Source - U.S. Dept. of Agriculture Farmers Bulletin No.2155, 1961.

[2] Maize grown each summer after winter rye/vetch cover crop.

[3] Maize grown each summer without cover crop.

6.3 CROP RESIDUES AND MULCH FARMING

Covering the soil with crop residues such as the straw and stubble of grain crops and grasses or banana leaves (see 6.2) reduce soil losses very considerably (see Table 6). Systematic use of mulches for soil erosion control and moisture conservation is known as mulch farming, mulch tillage, or stubble mulching. Under this system all or most of the residues from the previous crop are left on, or near, the surface of the soil. Mulch tillage for erosion control is of particular value when the crop itself, due to its habit of growth or spacing, does not protect the soil adequately. Crops grown in rows such as maize and sorghums are typical examples, also plantation type crops such as sisal and coffee.

Crop residues protect the soil from erosion by reducing the impact of rain-drops thus reducing the danger of surface sealing. Residues hold considerable amounts of water at the soil surface, and tend to retard surface flow, which allows more time for water to infiltrate into the soil. Table 6 taken from summaries of experiments carried out in the U.S.A. indicates the beneficial effect of mulches on the surface compared to ploughing in the residues in the soil.

Mulches tend to lower the soil temperature and control heat gains during the day and heat losses during the night. This is generally an advantage in warm to hot areas of low rainfall or during a dry season, but can be a disadvantage in wet cool seasons when maize seed germination may be retarded, (8). One problem is to prepare a satisfactory seed bed for a following crop when a mulch is already on the surface of the soil. A way of dealing with this is to run over the mulch with an implement such as a disc harrow and partially incorporate some of the residues in the top layer of soil. However, where suitable machinery is not available mulch farming with annual crops is somewhat laborious using only hand labour or light animal drawn machinery. For this reason it is not too popular with small farmers in the developing countries, but it should be encouraged under most conditions.

6.4 ROTATIONS

In section 6.1 it is shown that maize can be grown continuously on sloping land at a high level of production without any significant loss of soil or fertility; this holds true for other crops as well. However high level production systems of this nature do require considerable inputs which have to be found. Such inputs include heavy dressings of chemical fertilizers and/or organic manures, weed control by hand labour or machinery, chemical weed killers and perhaps chemical pest control. All this is possible provided the farmer has the knowledge, resources and services necessary at his disposal. The majority of small farmers in the developing countries, particularly those practising shifting cultivation, are not yet in this happy position. Therefore, for some time to come, every effort will have to be made to mobilize as much as possible nature's methods of maintaining soil fertility and controlling erosion. Rotations have much to offer in this direction.

The simplest rotation is the short period of cultivation followed by a long period of fallow as in shifting cultivation or non-continuous systems of farming described in Chapter 4. If the length of the fallow has to be reduced the problem is to replace it by a planted crop which is also economic. Thus the intensity of cropping would be increased while at the same time maintaining soil fertility, structure and controlling erosion. Planted grass or legumes or both together in rotation with annual crops are very effective for this purpose. Several annual crops may be grown in rotation first, commonly close sown cereal grains rotated with row crops and root crops followed by the ley. The ley is often sown together with the last grain crop. By the time the grain is harvested, the ley is already becoming established, which does away with the necessity to prepare a new seed bed for the ley. It also happens to keep the soil continuously covered with vegetation. Interesting results of 30 years experiments in Iowa in the U.S.A. show that, although erosion losses are reduced by growing maize with heavy dressings of nitrogen fertilizer, even less soil is lost by rotating the maize with a ley. (Moldenhauer et al. 1967. (22)

Apart from keeping the soil covered, leys improve soil structure and, if they consist of legumes, they fix nitrogen from the atmosphere. In temperate climates the soil crumb structure is built up slowly and remains stable, so that when the ley is ploughed in the structure persists for several years of subsequent cropping. Under tropical conditions it appears that leys produce a beneficial structure more rapidly, but the benefits are relatively short-lived, because the structure breaks down more quickly. This is largely due to the more rapid breakdown of organic matter in tropical soils.

The results of experiments in Africa using Cynodon plectostachyum (Star Grass), Pennisetum purpureum (Elephant Grass) and Eragrostis curvula (Weeping Lovegrass), in rotation with maize, tobacco and forage crops suggest that the residual erosion control benefit of the grass ley is best in the first year; some effect remains in the second year and none in the third year after ploughing in. However, as soon as the grass is established erosion is rapidly reduced and continues at a low level so long as the grass is left down. The conclusion is that maximum possible crop production and erosion control result from quick rotations - not more than two years of cropping after the ley and back again to a short grass ley. (5)

6.5 CONSERVATION TILLAGE PRACTICES

6.5.1 Minimum Tillage

It is known that intensive tillage of tropical soil leads to rapid breakdown of soil structure, more rapid decomposition of organic matter and loss of moisture, (see 2.4.3). Therefore the less the soil is tilled consistent with satisfactory crop husbandry the better. In this sense minimum tillage means the least tillage necessary to produce the crop.

Indigenous peoples of Africa and Asia have practised minimum tillage for a very long time primarily to save labour within the range of facilities and tools available to them. For example, in Africa in the Savannah zones it is common practice to dig holes with a hoe one pace apart and plant maize seed in each hole, without any other form of seed bed preparation. If there is grass in between the holes it is left untouched, or may be lightly slashed.

In temperate regions minimum tillage appears to denote the use of new and sophisticated farm machinery used singly or in combination so as to reduce operating costs. These costs include time, labour, energy and machinery maintenance.

6.5.2 Listing or Ridging

Listing or ridging are terms used to describe the formation of alternate furrows and ridges on the land. When listing or ridging is done on the contour it helps to conserve soil and water. When small dams are created at intervals in the furrow it is known as basin listing or tied ridging. This practice is referred to in more detail in 6.5.3. The ridges are made by using hand hoes, animal drawn ridging bodies or tractors fitted with ridging equipment for the growing of maize, sorghums and cotton in Africa and elsewhere. The following season the ridges are usually split down the middle, thus burying the crop residues in the new ridge (Figure 25).

FIGURE 25. - Splitting ridges with ox-drawn toolbar (TAMTU, Tanzania: Photo by I. Constantinesco)

6.5.3 <u>Basin Listing or Tied Ridging</u>

The creation of a multitude of small basins in a cultivated field is an effective way of retaining moisture and controlling both wind and water erosion in areas of low rainfall. The idea is not new and special machinery for the purpose had already been developed in U.S.A. in the early 1930's. The simplest way to create these basins is to set the land up in ridges and furrows and to build a small dam wall at intervals in the furrow with a mechanical or hand operated shovel device behind the listers. (See Figures 26, 27 and 28.)

FIGURE 26. - Hand operated ridge tying units at the Cotton Research Station, Namulonge in Uganda (31). (Photo courtesy of National Institute of Agricultural Engineering, U.K.)

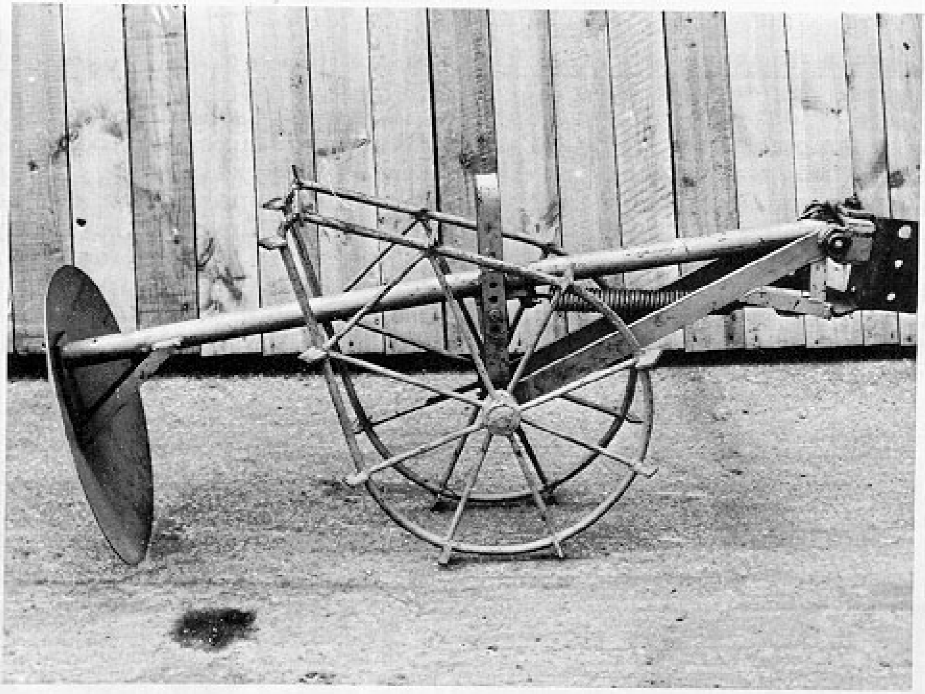

FIGURE 27. - Mechanical tying unit actuated by a land wheel for attachment to tractor toolbar, developed at N.I.A.E. in U.K., and based on a design by Farbrother at the National Cotton Research Station in Uganda (32). (Photo courtesy of the National Institute of Agricultural Engineering, U.K.)

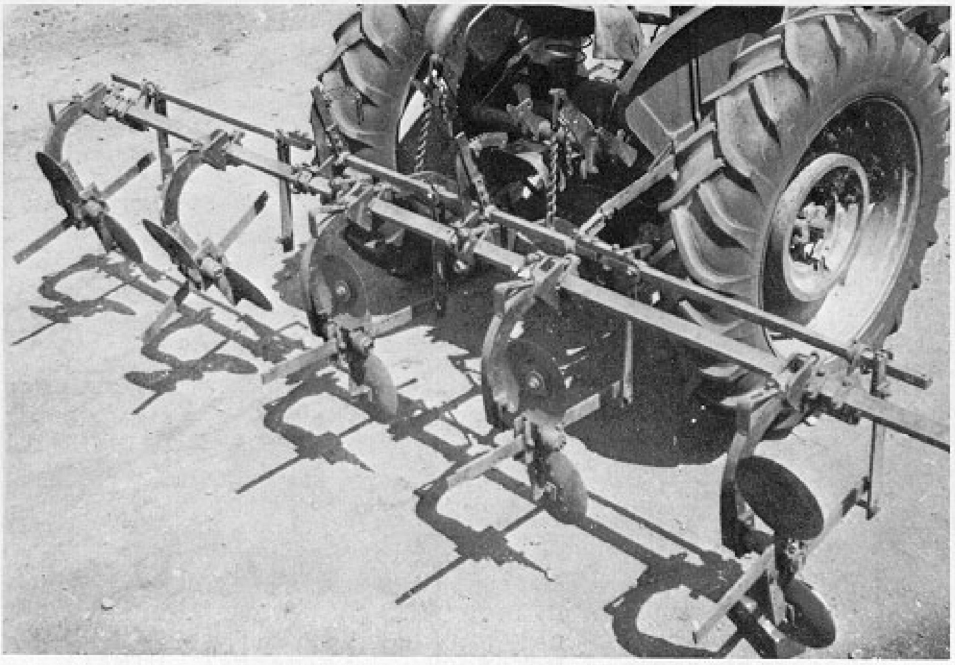

FIGURE 28. - Another type of mechanical tying device actuated by a trip which is operated by each revolution of the tractor wheels. (Tanzania: Photo by R. Minto)

The whole operation can of course be done with hand hoes, including making the ridges and the ties. It is common practice to build ridges by hand without tying in many parts of the Tropics but experience suggests that this is not proof against erosion, partly because hand built ridges are rarely accurately on the contour, which allows water to scour the channels, collect in low spots, overtop and break down the ridges.

Experience in various parts of the Tropics suggests that ridging alone, without tying, even when the ridges are accurately aligned on the contour, cannot be relied upon as full protection against soil erosion by water. For example, in Nigeria as long ago as 1938 Dudley Stamp referred to ridges as incipient gutters (24) and although Faulkner in Trinidad (1944) had shown that ridging accurately on the contour was better than any other system except tied ridging (25), Peat and Prentice recorded run-off from ridges spaced five feet apart and accurately on the contour on permeable hill sand soils in Sukumuland, Tanzania. (26) On the other hand when the ridges were tied there was no run-off and they concluded (in 1949) that no other method of soil conservation practice gave such complete protection against erosion in that area.

Two cases are recorded where good tied ridging was not convincingly more satisfactory than any other method for the control of soil erosion - at Ousseltia and Ouled M'hamed in Tunisia (27). In the first case very heavy rainfall over six days caused over-topping of the basins and some erosion, but land ridged without tying suffered more severe erosion. In the second case high winds over four days flattened the ridges and ties. This suggests that some supporting conservation practices might be necessary, such as diversions, terraces, wind breaks and better management of mulches.

In the cotton growing areas of Lake Region in Tanzania the idea of tying ridges by hand had already become established among the farmers in the late 1930's and early 1940's because they realized that this practice resulted in higher yields. The results of 14 trials from 1939 to 1946 showed that tied ridge plots of cotton, sorghum and maize outyielded flat cultivated plots every year except 1942 and 1945 (because those particular years had above average rainfall). The results in the other years were impressively in favour of tied ridging and in some years represented the difference between complete crop failure on the flat and an economic success on land ridged and tied. In fact the treatment effect in many cases was so large that the effects of manuring and crop spacing were only of secondary importance. Spectacular increases in the yields of cotton were again shown by Peat and Prentice in eleven trials from 1945 to 1947 on soils subject to drought in Ukiriguru in Tanzania, and also by King (28) in Nigeria in 1960. Lawes (29) reported encouraging results in Northern Nigeria from experiments carried out between 1958 and 1961.

From 1959 to 1963 McCartney (30) carried out a series of experiments on three soil types in Tanzania using a completely mechanized system for ridging and tying. (Figures 29 and 30.) He reported that tied ridge cultivation resulted in greater crop vigour and evenness on all three soil types in all years and tied ridging gave significantly higher yields than ridging without tying.

FIGURE 29. - Completely mechanized system for ridging and tying. The land is being set up directly into ridges and ties without first ploughing. (Photo courtesy of National Institute of Agricultural Engineering, U.K.)

FIGURE 30. - Similar equipment in use on the Cotton Research Station in Uganda splitting and retying ridges made the previous season.(Photo courtesy of National Institute of Agricultural Engineering, U.K.)

As to be expected, in soils subject to capping or in other ways of poor permeability, in areas of high annual rainfall, or in seasons of above average rainfall, yields may be depressed due to waterlogging, or ridges and ties may be damaged due to overtopping. In Tanzania McCartney tried what he termed subsoiling with the same equipment shortly after planting to help increase percolation in compacted and capped furrow basins. First he fitted subsoiling tines to work at six inches depth in place of the ridging bodies. This improved percolation but the profile of the ridge became concave following the shape of the tying disc unit giving a peaked top to the ridge, while the tying unit collected soft annual weeds forming small permeable ties. This disadvantage was overcome by fitting tines to the ridging (lister) bodies and thus subsoiling the furrow bottom at every ridging or weeding operation. (Figures 31 and 32). He concluded that ridging with subsoiling gave appreciably faster percolation, and found that the treated plots could be cultivated the day after a rain storm of 46 mm in two hours. On the untreated plots machine cultivation would have been impossible for at least three days.

Experience with this equipment indicates that when setting up ridges that will have to be re-ridged or split for several cropping seasons, the ridges must be accurately spaced.

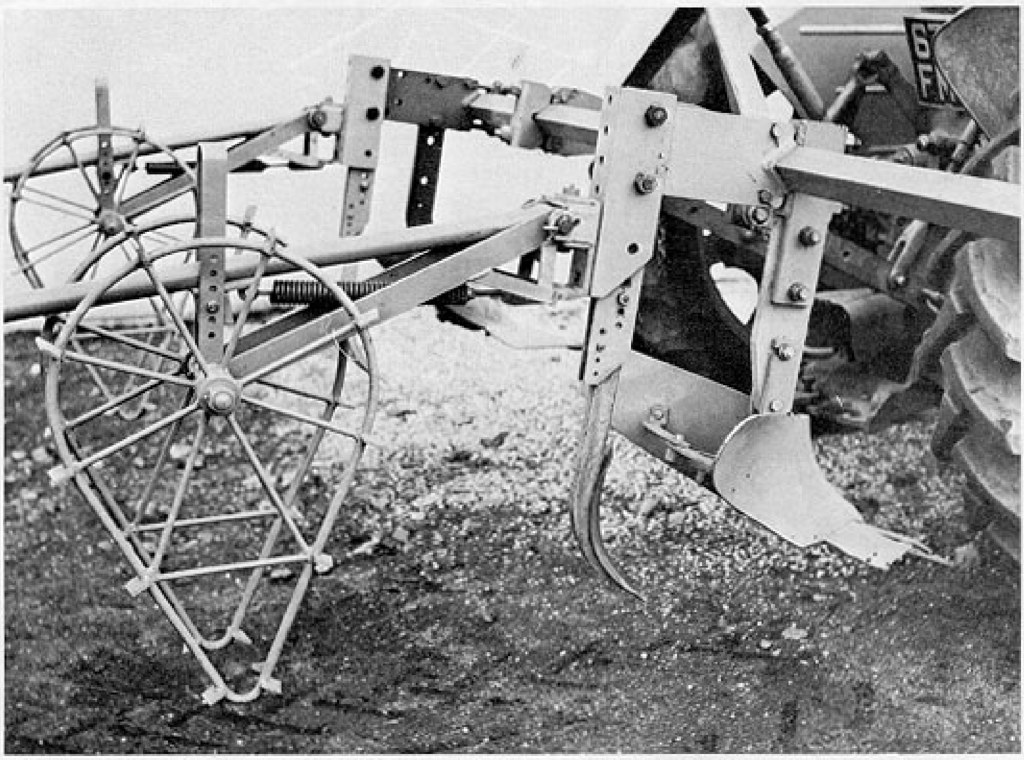

FIGURE 31. - Rigid subsoiling tine fitted behind ridging body, as used in trials in Tanzania. Note tying attachment at rear, (32) (33). (Photo courtesy of National Institute of Agricultural Engineering U.K.)

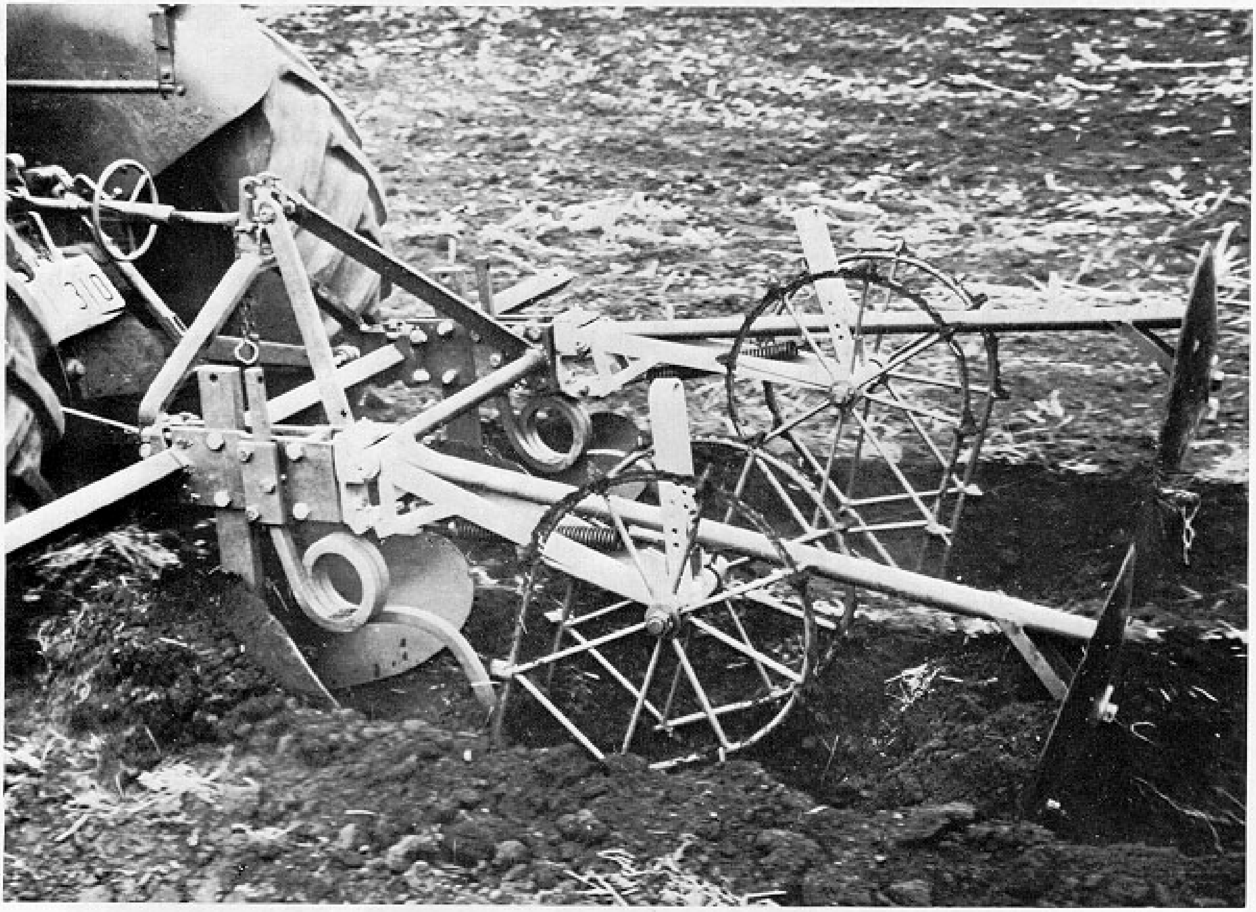

FIGURE 32. - Spring Tine subsoiler fitted behind ridging body. Note tying attachment at rear (32). (Photo Department of Agriculture, Queensland, Australia)

For splitting or re-building ridges tie breaking tines ahead of the tractor rear wheels are necessary. (See Figures 33 and 34.)

FIGURE 33. - Manually lifted tie breaker.(Photo Ministry of Agriculture, Forestry and Wildlife, (Tanzania).)

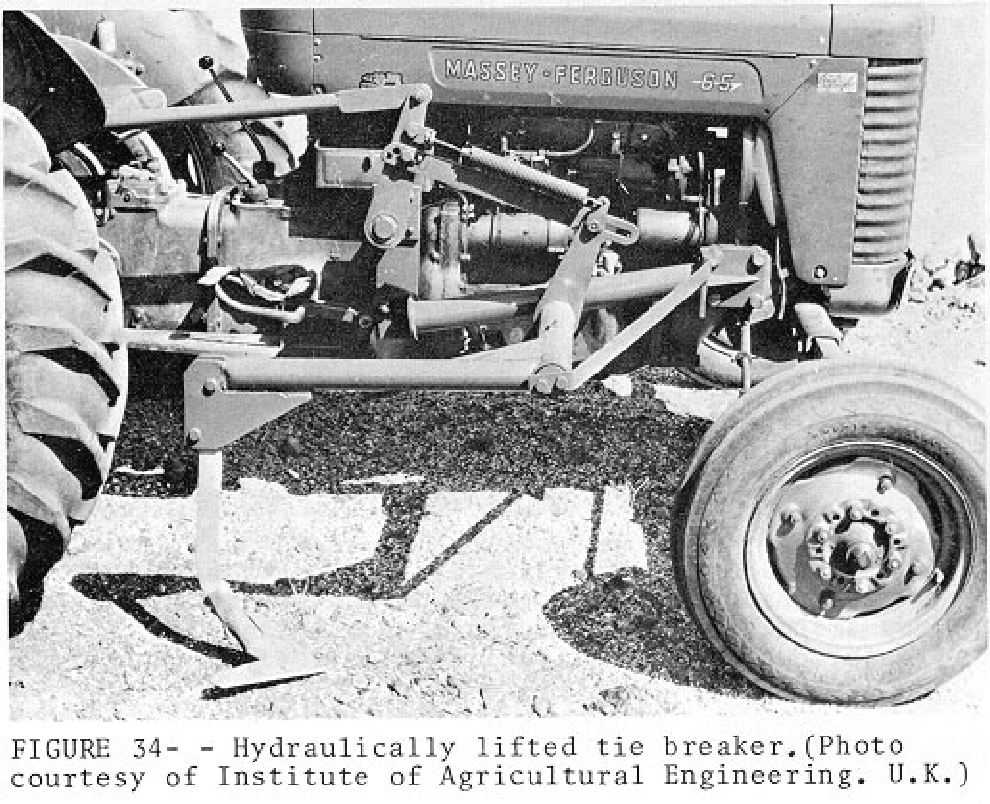

FIGURE 34- - Hydraulically lifted tie breaker.(Photo courtesy of Institute of Agricultural Engineering. U.K.)

The tie breakers do not work below the level of the tractor wheels and so need not normally be lifted except for transport, but they need a spring release mechanism to prevent damage by obstructions.

Planting can be carried out at the same time as ridging or splitting. When planting is done as a separate operation after ridging and tying, the breakers must be used, plus tying units to remake the ties. Toolbar depth wheels, if fitted, must also be run on the tops of the ridges, because they would bump over the ties in the furrow. (Figure 35.)

FIGURE 35. - Planting previously ridged and tied land at the Cotton Research Station in Uganda. In this case the maize stalks of the previous crop are placed in the furrows as a mulch. (Photo courtesy of National Institute of Agricultural Engineering, U.K.)

This complete cultivation technique aids in the control of soil erosion, soil moisture status, and promotes high crop yields. Such a tied ridge system appears to have great merit in areas of low or erratic rainfall.

A decade of experiments in East Africa, particularly in Tanzania and Uganda, show the benefits of tied ridging compared to ridging with no ties, and to flat cultivation on land not subject to waterlogging, whether the operation be carried out by hand or by machinery.

6.5.4 Subsoiling and Chiseling

Subsoiling or deep subsurface tillage is sometimes necessary to break up hard-pans, either natural ones or those developed by continuous ploughing at the same depth, to improve soil permeability and to promote plant root growth. For deep subsoiling powerful machinery with knife type or chisel tines are required which can penetrate 30 to 45 cm deep, or a gyrotiller which can stir the soil down to 75 cm. The benefits from the crop yield point of view in tropical soils appear to be uncertain. More convincing benefits arise from improved percolation of rainfall, reduction of run-off and control of erosion on sloping land by subsoiling across the slope or on the contour, and from improved penetration of irrigation water.

Subsoiling may be necessary before setting up ridges or tied ridges with lister bodies if the soil is hard, compacted and impervious. It may also be necessary from time to time when tied ridge cultivation becomes a regular practice. (See Figure 36 and 37.)

Experience in East Africa and Nigeria in the cultivation of hard soils in the dry season, particularly those known as cementing sands and heavy black clays ("black cotton soils") shows that it is almost impossible to cultivate these soils by hand except laboriously with a heavy sharp pointed iron implement such as a crow bar. An example of sorghum planted with a crow bar in heavy black clay soil in Nigeria is shown in Figure 38. It is also difficult and sometimes impossible to cultivate such soils with mouldboard or disc ploughs. Under these conditions it is often necessary to use heavy duty rigid or spring tines fitted to a toolbar or to a heavy trailed chassis (Figures 39 and 40). In this form the outfit is often referred to as a chisel cultivator or chisel plough, although the latter term is more generally applied to the spring tined version. The advantage of chisel ploughing from the soil conservation point of view is that it does not bury the mulch. The land is also left in a rough cloddy condition which helps to control wind erosion during dry periods and assists infiltration of water when the rains start.

If the soil has a very hard cap, it may be found that rigid tines will not penetrate. Under these conditions heavy duty spring tines may be more successful due to the vibratory action of the springs which break the surface cap.

FIGURE 36. - Subsoiling previously ridged land, Uganda. (Photo Courtesy of National Institute of Agricultural Engineering U.K.)

FIGURE 37. - Subsoiling tine integral with lister body. (Photo Ministry of Agriculture Forestry and Wildlife, Tanzania.)

FIGURE 38. - Sorghum planted with a crow bar in heavy black clay soil, Nigeria . (Photo Land Resources Division, Ministry of Overseas Development, U.K.)

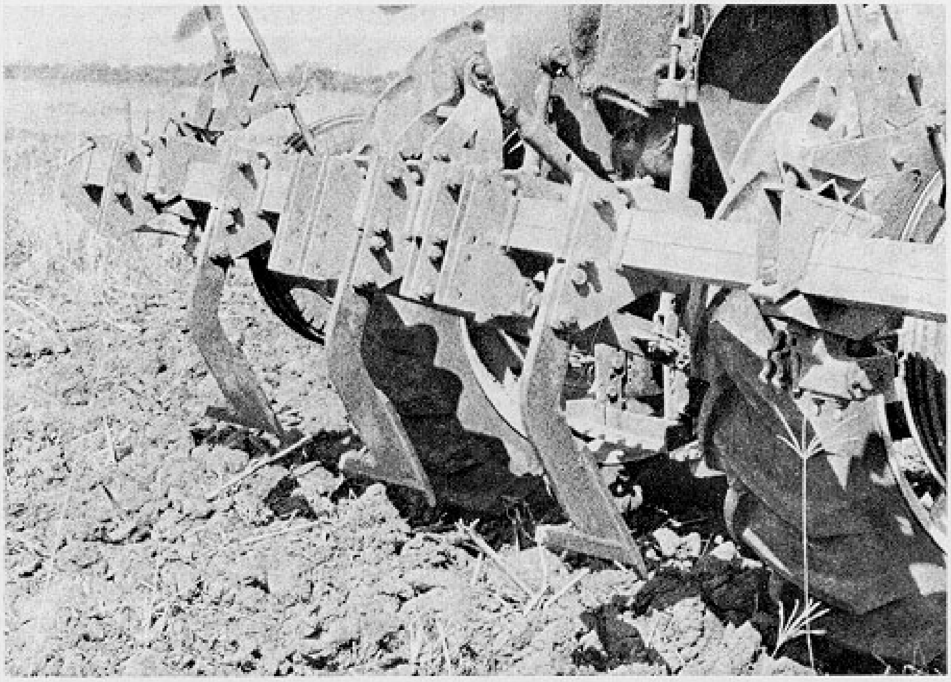

FIGURE 39. - Rigid subsoiling tines suitable for primary cultivation fitted to the same toolbar used for tied ridging equipment. (32) (Photo courtesy of National Institute of Agricultural Engineering, U.K.)

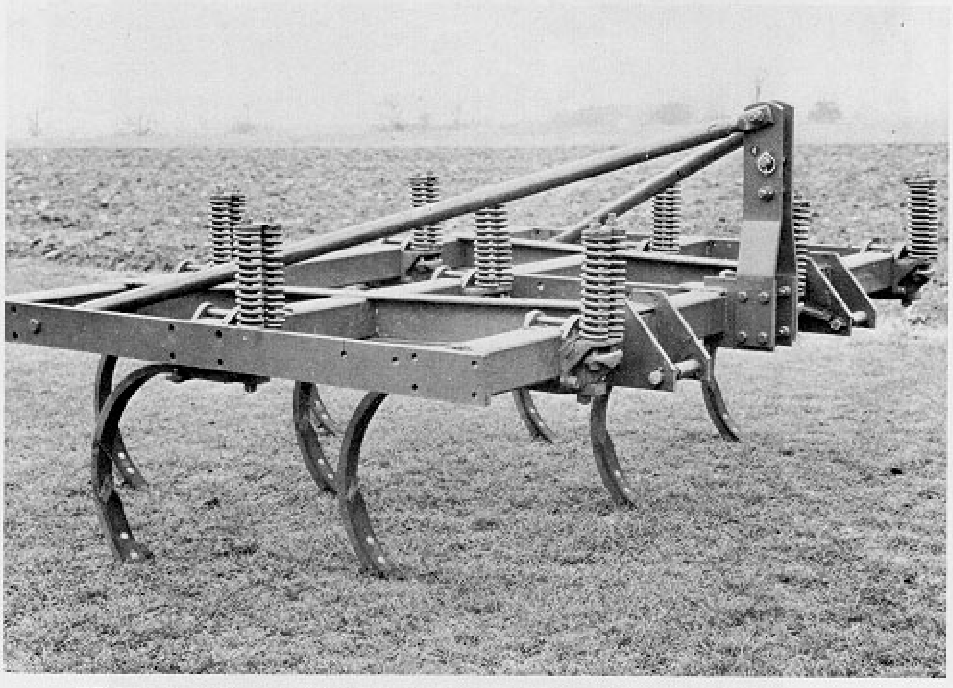

FIGURE 40. - Example of heavy duty spring tined chisel plough. (Photo courtesy of National Institute of Agricultural Engineering, U.K.)

The question may be asked - why try to cultivate in the dry season and why not wait until rain falls when the land will be soft? If production is to be increased substantially timeliness must be achieved and this can only be done on those soils by mechanization. The second reason is that tractors and implements cannot work in these soils when they are wet due to wheel slip or bogging down, apart from the damage they cause to clay soils by compaction. Thus heavy duty chisel ploughs operating when the soil is dry appear to be the only solution. Unfortunately they need high powered tractors to operate them and they are expensive to run and maintain.

6.6 STRIP CROPPING

Strip cropping is one of the more simple additional measures which may be employed to provide protection to the soil singly or in combination with one or more of the agronomic and tillage practices described in the previous Sections. In general terms strip cropping means dividing land into alternate strips of close growing erosion resistant plants such as grass, grass/legume mixtures, small grains or natural vegetation with strips of wider spaced crops such as maize, sorghums, cotton and root crops.

6.6.1 Rotational Field Strip Cropping

Rotational field strip cropping may be employed to maintain soil fertility as well as to control soil erosion. An application of the principle in forest reserves (Taungya) and on lands of shifting cultivation in forest areas is mentioned in Chapter 4. The same basic principle may be applied to natural or planted grasslands. To facilitate rotation the width of grass and arable strips should be equal. On relatively flat land the system may be used to control wind erosion as well by orientating the strips at right angles to the prevailing wind. It can also be used to help control rainfall erosion on sloping land by laying out the strips approximately along the contour or across the slope. The grass absorbs rainfall and slows down the velocity of run-off and thus gives a degree of protection to the cultivated strip below.

The problem is that if the cultivated strips are too wide and the slope too steep the cultivated strips may themselves suffer from rainfall erosion and the soil removed will be deposited along the top part of the next grass strip forming a bund or terrace bank. This is not necessarily a disadvantage providing the top soil is deep and the loss to the bank does not materially affect the growth of the crop. However if there is only a thin layer of top soil and/or a young crop is just emerging followed by a heavy rainstorm, subsoil may be exposed and several lines of crop may be washed out at the bottom end of the strip (Figure 41). The solutions are: first to narrow the strip; secondly it may be necessary to apply additional measures to the cultivated strip, such as mulching, ridging or tied ridging.

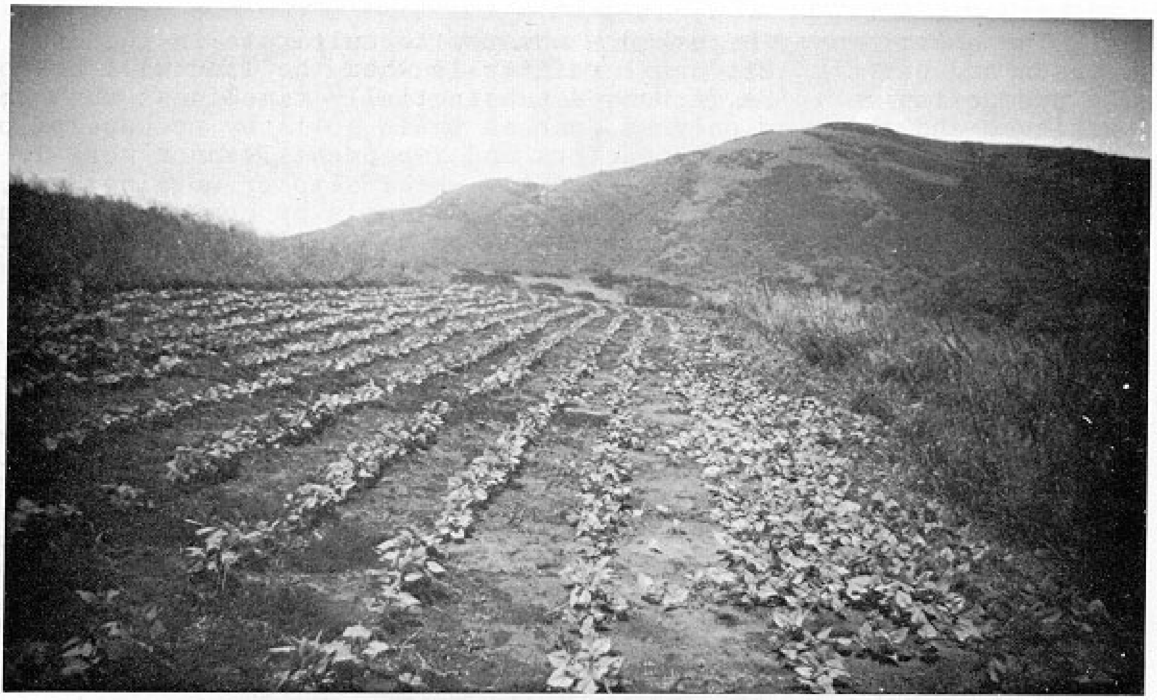

FIGURE 41. - Rotational Field Strip cropping across the slope with natural grass. Note erosion and wash out of young beans towards bottom end of cultivated strip because width was too great for the slope.
(Tanzania: Photo by I. Constantinesco)

There is no hard and fast rule as to how wide these strips should be. It depends on such factors as absorptive capacity of the soil, density of grass growth, or cover, intensity of rainfall and slope. As a general guide the width of strips vary from about 10 to 20 metres and are considered suitable up to about 5 percent of slope. The system may be successful on slopes greater than 5 percent if good farming is practised and other supporting measures such as mulching and tie ridging be employed. It has the advantage of being simple and inexpensive to apply, using normal hand cultivation methods, animal powered implements or tractors. Figures 42 and 43 show examples of rotational strip cropping with natural grass fallow across a gentle slope in Tanzania. The mean annual rainfall in this location is about 800 mm and it is bimodal, falling mainly in November and December and in March to May. Rainstorms of around 180 mm over 12 hours are fairly common.

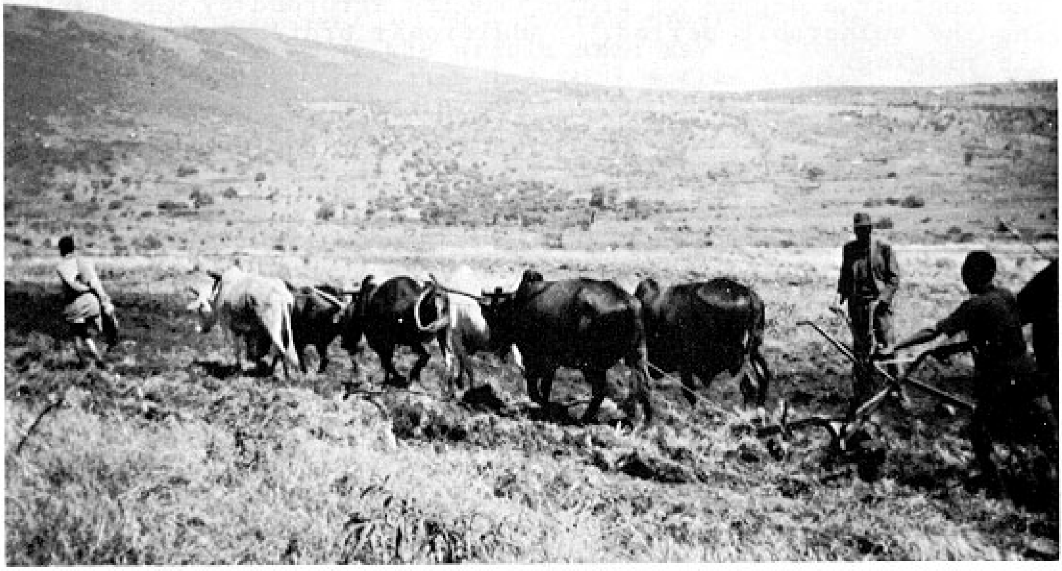

FIGURE 42. - Field strip cropping across gentle slope, using a team of oxen to plough the cultivated strip.
(Tanzania: Photo by I. Constantinesco)

FIGURE 43. - Sorghum/grass rotational field strip cropping across gentle slope.
(Tanzania: Photo by I. Constantinesco)

The cultivated strip may be cropped for one to two years, then the grass strip is cultivated and the previously cultivated strip may be left to fallow or be planted with a grass or grass/legume mixture. As cultivation is done across the slope and approximately on the contour a degree of protection is afforded by the furrows during the vulnerable period. Additional protection may be given by tie ridging.

A terrace bank can be deliberately encouraged to build up by laying crop residues along the bottom end of the cultivated strip where it joins the fallow strip. (See Figure 44.)

FIGURE 44. - Rotational field strip cropping. Deliberate formation of vegetative banks between cultivated and fallow strips. (Tanzania: Photo by I. Constantinesco)

This system of rotational strip cropping has much to commend it because it limits the period of fallow to one to two years. This is a great improvement over a traditional shifting cultivation system. If terraces are deliberately allowed to develop, the grass fallow may be eliminated. The soil will be stabilized through the gradual reduction in slope on the farmed area and protection of the vegetative bank. However other measures have to be taken to maintain the soil fertility previously supplied by the long ley under the shifting cultivation system.

The grass strip can be utilized by adapting the system to mixed farming - crops and livestock. The grass strip can be grazed, cut green for fodder or be made into hay. Livestock need to be prevented from wandering into the growing crop in the cultivated strip.

6.6.2 Buffer Strip Cropping

Buffer strip cropping differs fundamentally from rotational field strip cropping in that the grass strips, whether natural or planted are usually permanent. This system provides a degree of erosion control while most of the arable area may be cropped, because buffer strips are rarely more than 1·2 to 3 metres wide. These narrow strips have limitations in controlling erosion because run-off and silt may penetrate through to the cropped area below. They can be made more effective by planting strong dense growing grasses such as Panicum maximum, supported by a trash barrier along the upper edge of the grass strip. This will allow some water to percolate through if pressure builds up but silt will be held back.

Provided that terracing is acceptable, the best results will be obtained by laying out the grass strips along the contour at the correct vertical interval for terraces in the area concerned.

If accurate contouring is applied and the slope is relatively steep and non-uniform the width of either the grass or the cultivated strips will vary. To simplify cultivation by animal or tractor operated machinery it is preferable for the width of the grass strip to vary, keeping the width of the cultivated strip uniform, as shown in Figure 45.

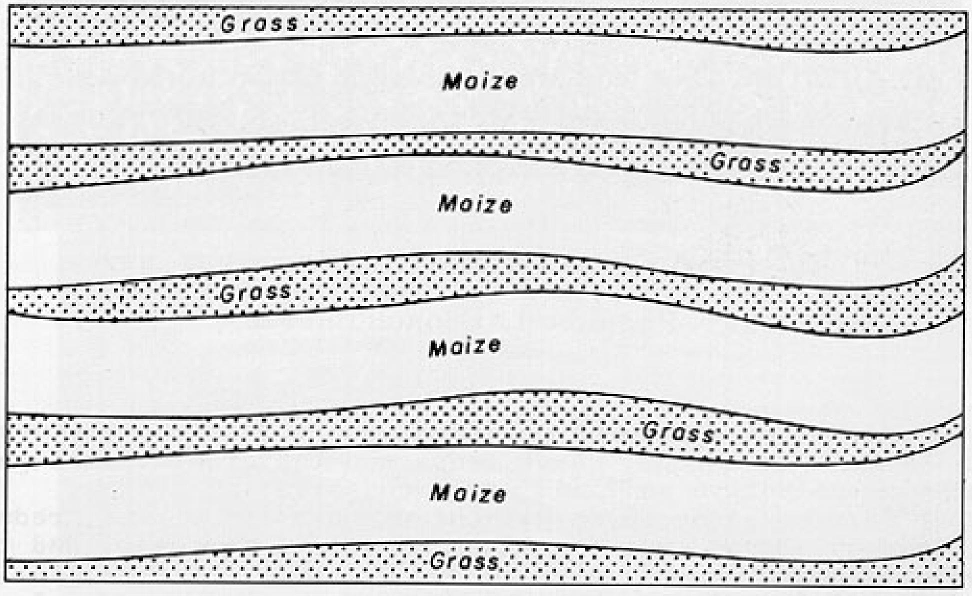

FIGURE 45. - Diagram of buffer strip cropping on the contour.

6.6.3 Contour Strip Cropping

The term contour strip cropping refers to a system of farming which includes three main elements: the first is that all strip cropping of whatever kind is done as nearly as possible on the contour; the second is that tillage and planting are also done on the contour. The third is that the crops may be rotated on the same strips, between strips, or both. The use of suitable survey equipment plus trained personnel are desirable to lay out the contour lines and more skilled tractor operators are required to do the cultivations. The system is supported where necessary by terracing and other measures. Contour strip cropping has been used with success on steep slopes in various parts of the world. (Figure 46.)

FIGURE 46. - Contour strip cropping maize and grass, on a 23 per cent slope.
(Tanzania: Photo by I. Constantinesco)

Contour strip cropping combined with rotations, the use of fertilizers and manures, cover crops and the growing of legumes is usually an effective soil and water conservation system. The contour farming alone, even without any barrier strips, reduces soil loss by 50 per cent on slopes of 4 to 6 per cent, and the loss of water through run-off is also cut by half. A five year study of 260 farms in Iowa indicated that farming on the contour alone increased the yields of maize, soybeans and oats by 7·3, 2·5 and 5 bushels per acre respectively. Other results of investigations in the U.S.A. indicate that if contouring and strip cropping are combined, soil loss is reduced by 70 to 75 per cent compared to up and down hill cultivation (8).

Note - 1 bushel = 35.24 litres approx.

For mechanical cultivation, the width of strips should be adjusted to provide a convenient multiple of the width of working of the farm machinery. If the slope is not uniform, it has to be decided which strips will be of uniform width and which will vary. As a general rule it is more convenient to ensure that the strips which are the most cultivated with row crops be uniform in width so as to avoid point rows. In practice the width of strips will vary according to soil, climate and slope, and other local conditions. Therefore, it is not possible to arrive at a universally applicable formula for designing width of strips, but Table 7 may be used as an initial guide-line for soils that are fairly permeable.

TABLE 7

Guide to strip widths (8)

Per cent slope	Strip width in metres
2 - 5	30 - 33
6 - 9	24
10 - 14	21
15 - 20	15

A typical example of contour strip cropping with supporting practices applied to a whole farm in U.S.A. is shown in Figure 47.

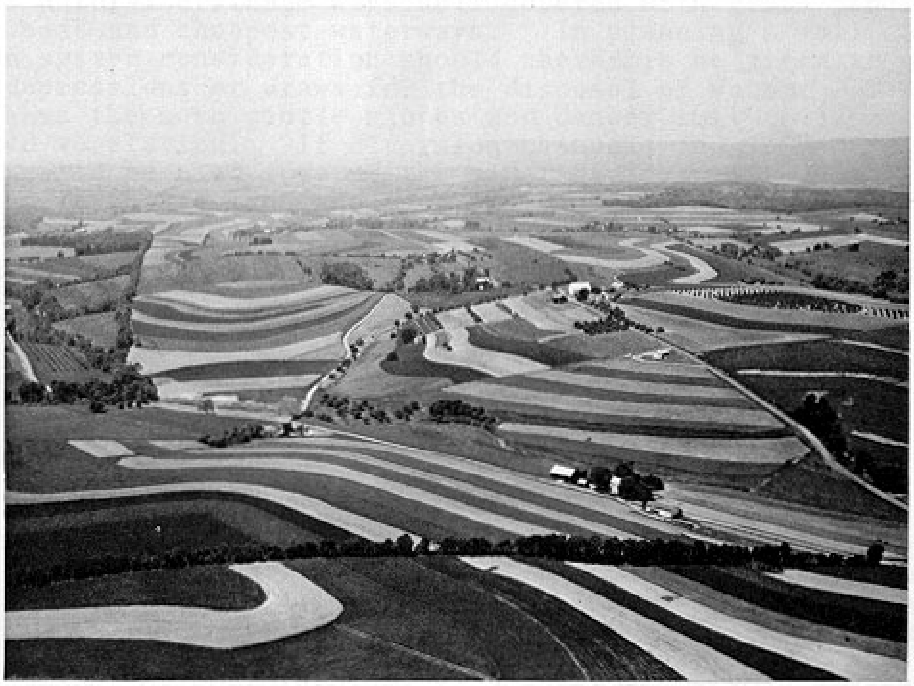

FIGURE 47. - Contour strip cropping in combination with terraces with alternate strips of maize and wheat and grass and oats on farms in U.S.A. (Sunbury Pa. Photo courtesy of USDA Soil Conservation Service)

In areas of traditional farming and shifting cultivation in the developing countries the vast majority of farms are small and may be fragmented. Therefore the application of comprehensive contour strip cropping depends on the agreement and co-operation of all farmers in the area concerned. It also involves a change from non-continuous to continuous forms of agriculture, the acquisition of some technical knowledge and the co-operative use of farm machinery.

The benefits in the form of soil and water conservation and increased crop yield may be great compared to the cost. There is no increased cost to the farmer except the laying out of the contour lines, and in most cases this should be done for him by the local extension or soil conservation service.

6.7 DIVERSIONS

Diversions or diversion channels are essential as the first line of defence for the protection of cultivated areas if there is a danger of damage by extraneous run-off. This holds good no matter whether the cultivated area be bare, cropped or under some form of soil conserving management practice such as strip cropping or a terrace system. Consideration must also be given to the treatment of land above the diversion to reduce run-off and sediment production. Diversions may also be used to control gullies. (Section 6.10.)

A diversion is a graded channel or ditch somewhat similar to a graded channel terrace designed to intercept surface run-off and convey it safely to an outlet or waterway. It is usually larger in capacity and may have a steeper gradient than a terrace.

FIGURE 48. - Example of diversion channel with other soil conservation practice, in this case trash bunding. The bank is planted with Napier grass (Pennisetum purpureum) to strengthen it and to provide fodder. (Tanzania: Photo by I. Constantinesco)

Many farmers throughout the world are familiar with the need to divert run-off from their cultivated fields and there are ample examples of this type of structure variously known as diversion ditches, storm drains and so on. (Figure 48.) Sometimes several of these structures may be seen across hillsides. In areas of the world where farmers are accustomed to handling water, surface drainage and irrigation channels may be found which are remarkably accurate in gradient and capacity, which have been laid out by eye and dug without any formal knowledge of open channel hydraulics. In other areas, particularly where there is no history of expertise in irrigation, the results have not been so successful and cases of broken-down and abandoned channels may be seen. The cause is usually insufficient capacity and/or too steep a gradient. The danger of failure and increased erosion which can result from incorrectly designed channels can be minimized by the application of the principles of open channel hydraulic engineering. Designing from first principles involves somewhat lengthy and advanced mathematical procedures and the estimation of many variables. The use of these procedures provides a better chance of success than relying on guess work and hunches. Details of these design procedures are not within the scope of this Bulletin. (See references 36, 37, 39.)

6.8 WATERWAYS

Waterways are widely used in soil conservation practice to conduct run-off safely to a larger drainage way. They serve as outlets for diversions, graded channel terraces or some types of bench terraces. However, even if no specific terrace system is in use or contemplated, there will be run-off to be disposed of safely.

Wide natural drainage ways well covered with grass generally form the best and cheapest waterways. In planning a soil conservation system consideration should therefore be given to utilizing natural depressions or draws for the disposal of water. The draws usually have the more gentle slopes and deeper soil to foster natural or planted vegetation. If diversion channels and graded terrace systems are to be used some of the minor drainage ways may be eliminated in the design, and thus less waterways will be needed. Sometimes it may be possible and convenient to shape a gully, plant it with grass and use it as a waterway. This is one way of saving gullies from further deterioration.

If run-off from diversions and terraces has to be concentrated into a natural drainage way it may be necessary to increase its capacity by shaping. If no suitable natural drainage way is available an artificial one may have to be constructed. In order to handle the volume of run-off without suffering erosion, waterways should be wide enough and shallow enough to allow the water to flow in a thin sheet. The steeper the slope the wider they should be in order to spread the water and retard velocity. However grassed waterways on very steep slopes would have to be so wide as to be impractical. Under these conditions a different design incorporating let down structures such as falls or chutes etc. has to be employed.

The amount of work involved in shaping a waterway depends upon the topography and equipment available. If a natural draw is to be used and there is little gullying, only smoothing to the required cross section may be necessary. The channel may have to be realigned slightly to remove sharp bends. Where an established gully is to be used as a waterway, considerable earth moving may be necessary because the gully must be filled and the cross section established. For this work a heavy bulldozer is generally the best tool to use. Small waterways can be shaped by hand tools or animal and tractor operated implements such as ploughs, scrapers and small dozer blades.

After the waterway has been shaped, the soil should be fertilized with organic or chemical fertilizers and a seedbed prepared. The main problem is to get the channel covered with growing vegetation as soon as possible. Quick growing annual grasses may be sown as a temporary measure in addition to establishing locally adapted grasses. by planting, spot sodding or sodding (Cynodon dactylon - Bermuda grass will grow in most places). Additional protection can be provided by mulching the channel. Under difficult conditions it may be necessary to exclude water from entering the waterway until the vegetation is well established. This may be done by constructing side dykes around the waterway. The side dykes must of course be removed as soon as possible. If run-off has to be diverted into the channel soon after construction, the only solution may be to sod the channel first.

Once the cover for a waterway has been established it must be properly managed. On no account should animals or people be allowed to use the waterway as a path or road. If passage is required in the vicinity of the waterway, this need should be taken into account in the design, and an area provided alongside the waterway for that purpose. Great care must also be taken when moving vehicles and farm machinery across the waterway to ensure that the sod is not damaged. Damage to the sod must be repaired without delay. The grass must be well managed to ensure a strong dense stand of vegetation for controlling erosion.

6.9 TERRACES

6.9.1 General Considerations

Soil conservation terraces are artificial earth embankments or combined channels and embankments constructed across sloping land at fixed vertical intervals down the slope. The most ancient forms of these earthworks, still widely used in many parts of the world today, are bench terraces. Terraces cut sloping land into narrow segments, the effect of which is to reduce the length of slope.

Channel terraces constructed on the contour impound rainfall and run-off and encourage the water to infiltrate into the soil. Channel type terraces with a gradient intercept and dispose of excess rainfall and run-off to outlets at safe velocities. There is no loss of land with certain channel type terraces because the whole of the terrace is shaped so that it can be cultivated and cropped, in contrast to bench terraces, where the steep bank is lost to cultivation. However channel terraces of this type are limited to much more gentle slopes. Terraces which are constructed by hand labour or machinery are expensive because of the earth moving involved. The design layout and subsequent construction must be done accurately, and then the finished work must be maintained. More damage can be caused to the land by improperly spaced, inaccurately surveyed and constructed terraces than by no terraces at all. If there are low spots water will concentrate in these areas and may cause the bank to break.

As soon as one bank is breached water rushes through and adds to the pressure on the weak parts of the next terrace down, which in turn gives way. The end result may be the breaching of all terraces in the system and the formation of gullies.

Terrace systems, to be successful, must be part of an overall soil conservation and water disposal plan in the whole of a catchment. The plan must include all terraces that may be constructed at a later date. This means that comprehensive terrace systems can only be applied either on very large individual farms, or, as in the case of contour strip cropping, with the agreement and participation of all the farmers.

Having regard to the limited technical knowledge, trained manpower and finance available in areas of traditional and shifting cultivation, great caution needs to be exercised in the selection of terrace systems as a means of soil conservation. There is not only the problem of cost to consider but also whether terraces are really necessary. In areas of high population pressure and steep slopes, there may be no alternative to bench terraces, as many indigenous people have already discovered for themselves. In any case the more modern type of channel terraces are not practical on slopes above 20 to 25 per cent. Therefore every other crop and soil management practice or combination of practices which are simple and less expensive should be applied first.

6.9.2. Bench Terraces

Bench terraces convert sloping land into a series of flat or nearly flat platforms or steps. These steps may be long, level or graded, or in the form of short staggered platforms (Figure 49). The result is a reduction in both the effective length of slope and the gradient of the cultivated land on each terrace. This feature enables very steep land to be cultivated.

Bench terraces have been in use since ancient times in many parts of the world, notably in Latin America, the Mediterranean and the Far East. They tend to be found mainly in mountainous areas of high population where there is a shortage of land suitable for cultivation in the valley bottoms. An example in Nepal is illustrated in Figure 49. Here, it is impossible to cultivate the valley bottom due to heavy monsoon floods and the farmers have no alternative but to terrace and cultivate the steep mountain slopes.

Depending on conditions the terrace walls may be built of stone, as in the example from Cyprus in Figure 50. The construction of these terraces needs much labour and skill in building the dry walls, but as in Cyprus, this system has enabled formerly barren and hilly land to grow fruit trees and vines.

FIGURE 49. - Staggered bench terraces on a hillside overlooking flooded valley bottom in Nepal. (FAO Phot by R. Vroom)

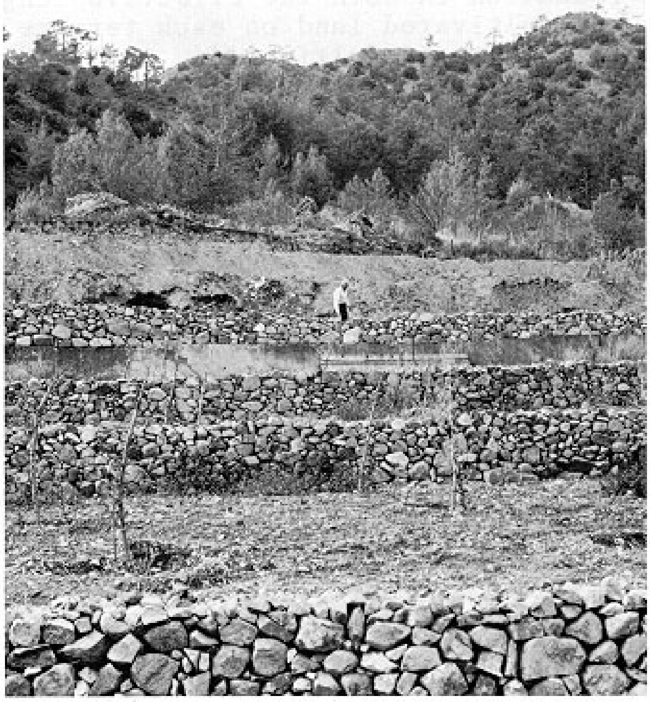

FIGURE 50. - Stone-wall bench terraces in the Troodos mountain region in Cyprus. (FAO Photo by J. Ciganovic)

Bench terraces with bare earth or vegetated banks are common on hillsides in many parts of the world. An example of hand built level terraces with grass banks cropped with maize is shown in Figure 51.

FIGURE 51. - Level bench terraces cropped with maize in Tanzania. (Photo by I. Constantinesco)

Irrigation terraces are extensively used in the Philippines, Japan and China, particularly for rice growing. These irrigation terraces have a raised lip or bank along the front edge to retain the water. They may be exactly on the contour for still water flood irrigation or have a fall for intermittent or running water gravity irrigation. A combination of these forms in use in Japan is shown in Figure 52.

It must be stressed that bench terraces, like any other form of terrace, must be carefully laid out, constructed and maintained. Failure to observe these requirements can lead to complete destruction of the terrace system due to the breakdown of the banks by run-off, an example of which is shown in Figure 53.

FIGURE 52. - Bench Terraces under rice in Japan. (Photo by I. Constantinesco)

FIGURE 53. - Breakdown of terrace banks due to poor design and lack of maintenance in Java, Indonesia. (FAO photo by H. Hull)

In addition to the need for accuracy and maintenance bench terraces are expensive to construct. On the other hand the amount of flat or gently sloping land available for cultivation is decreasing while populations are increasing. It would appear therefore that there will be a call to convert more steep hillsides into bench terraces. It must be realized however, that this can only be done successfully where the soil is sufficiently deep and stable. If the soil is too shallow, crops will not grow well on the sub-soil exposed. If the soil is unstable the whole terrace may collapse. This problem is not unknown to some of the indigenous farmers in the tropics. In parts of Africa for example, one solution is to lay rows of crop residues across the slope at intervals of about one metre and to cover the rows with soil about half a metre high. The result is a series of small back-sloping terraces containing a core of crop residues (somewhat similar to split ridges) and often known as ladder terraces. These small terraces appear to have stood the test of time on very steep slopes in areas of high population and high rainfall. Apart from the terracing effect, the core of crop residues helps to maintain soil structure and fertility.

The unpopularity of bench terraces, even on suitable soils, is often due to the arduous labour involved in construction. However, satisfactory bench terraces can be formed over a period of time with very little extra expenditure of energy. A method successfully developed from a system indigenous to Uganda and extended to Tanzania, relies on live barrier hedges of tall grasses and/or lines of trash placed across the slope or along the contour. These barriers act as a soil conservation measure in their own right, because they hold up silt but allow run-off to percolate through at a much reduced velocity. The slow downward movement of soil by controlled erosion results in the gradual development of bench terraces. The process can be accelerated by continuous downward ploughing of furrow slices; the process takes 5 to 7 years, depending on soil, crops grown and rainfall. (Figure 54.)

FIGURE 54. - Early stage of formed bench terraces using trash as the barrier. (Tanzania: Photo by I. Constantinesco)

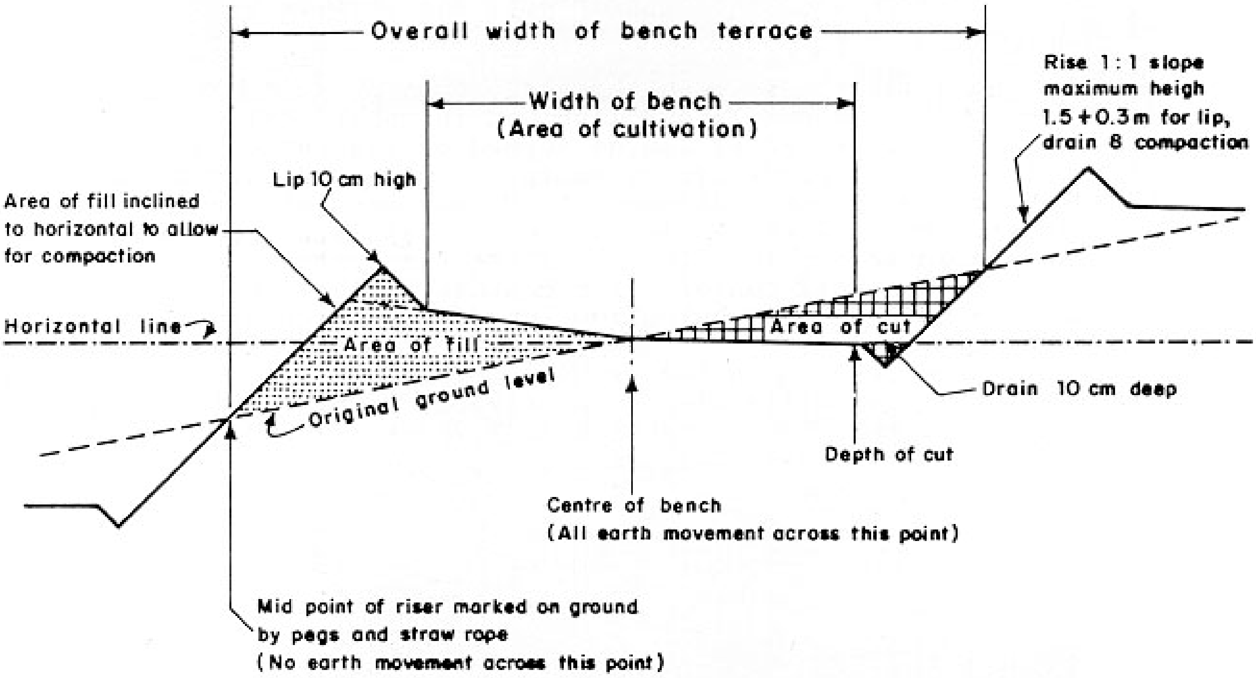

FIGURE 55. - Typical cross section for back-sloping bench terrace (38).

TABLE 8

Guide to design and construction of bench terraces with 1 m vertical interval (38)

Slope of land	%	5	10	15	20	25	30	35
Width of benches available for cultivation	m	18.50	8.50	5.17	3.50	2.50	1.83	1.36
Total width of bench terraces	m	20.00	10.00	6.67	5.00	4.00	3.33	2.86
No. of benches per 100 m of slope	-	5	10	15	20	25	30	35
Maximum depth of cut (excluding drain)	m	0.47	0.45	0.42	0.40	0.37	0.35	0.32
Area of benches available for cultivation per ha	%	0.925	0.850	0.775	0.700	0.625	0.550	0.475
Slope area of riser per ha	m^2	919	1838	2758	3667	4596	5515	6434
Volume of cut per ha of bench terraces	m^3	1175	1135	1077	1020	963	903	847
Slope area of riser per ha of benches	m^2	994	2162	3559	5253	7354	10027	13545
Volume of cut per ha of benches	m^3	1270	1335	1390	1457	1540	1642	1783

There are several advantages to this system: it has a high acceptance rate by farmers because little extra work or expense is involved; there is no build-up of pressure because excess water can percolate through the porous banks; low spots are soon filled with silt, so that even if the contour line is not accurate, it levels itself in time. The mulching effect of the crop residues encourages dense vegetative growth, which strengthens the bank. After the terraces have been developed fully there is no further need to place crop residues along the top edge of the bank, but it must of course be maintained.

A back-sloping bench terrace on the contour is desirable in areas of low rainfall so as to conserve all the rain that falls. For rain fed crops in areas of high rainfall it is necessary to avoid water logging by disposing of excess water. In order to achieve this the terraces should be graded so as to allow excess water to drain to a waterway. A slight back slope is also an advantage, and a lip along the front of the terrace to prevent over-topping of the bank and erosion of the risers. A small channel along the base of the riser is advisable to improve drainage. Earth banks or risers should be vegetated and have sufficient slope to maintain stability.

Design of bench terraces vary widely according to soil type, depth, climate and slope. Assuming however that the soil is sufficiently stable, and deep enough, a suitable general purpose design of terrace would have a cross section as shown in Figure 55. To ensure stability the risers have a slope of 1:1. Due to limited depth of soil it is rarely practical to have a vertical interval between each terrace of more than one metre. This means that on slopes of 20 percent or more the width of bench available for cultivation will not exceed 3.5 metres (11.5 feet), which is suitable for only hand cultivation. On slopes of 5 to 10 percent the terraces would be wide enough for mechanical cultivation and the vertical interval may be reduced so that the terrace width corresponds to the spacing requirements of crops and operating widths of machinery.

A guide to the design and construction of bench terraces with a one metre vertical interval and a cross section as shown in Figure 55 is given in Table 8. This table shows the relationship between the slope of the land and the width of terraces and the volume of soil that must be moved. From this it is possible to estimate the cost of construction in terms of local rates for hand labour or machinery.

6.9.3 Channel Terraces

Channel terraces consist of an earth bank and a channel on the top side built along the contour or with a gradient. Terraces on the true contour, known as absorption terraces, are suitable for areas of low rainfall. They intercept and hold water and thus help it to infiltrate into the soil. These terraces are usually closed at the ends, but where there is a danger of sudden intense storms there may be controlled outlets to allow excess water to drain away. Terraces which have a slight fall or gradient are intended to dispose of surplus run-off safely to a waterway and they are commonly known as graded terraces. Broad based channel terraces, as the name denotes, have a broad channel and bank (up to 15 metres or so) the whole of which can be cultivated by machinery. The widths of these terraces are usually adjusted to multiples of the working widths of farm machinery. They are only suitable for very gentle slopes and large farms. Narrow-based terraces have a channel and bank only 3 or 4 metres wide (Figure 56), and may be used on steeper slopes. The back slope should be permanently vegetated. They also cause benching of the land after a period of time.

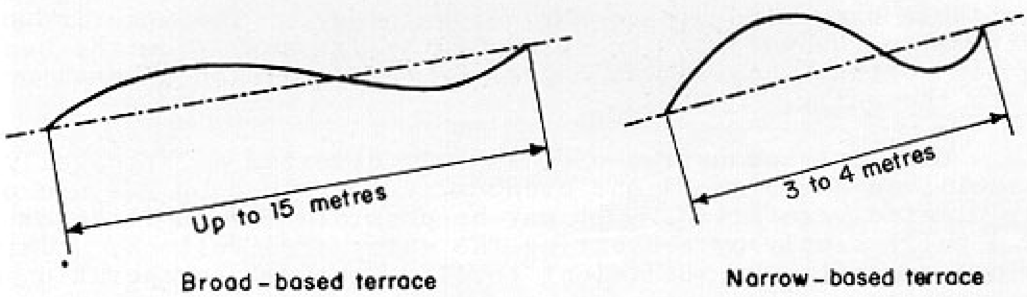

FIGURE 56. - Cross sections of broad-based and narrow-based channel terraces.

The type of channel terrace to use depends on soil, slope, climate and farming system. Broad based terraces are certainly only suitable for very gentle slopes, large farms, and where suitable machinery is available for construction and subsequent farming. Narrow based terraces also need machinery to construct them and large farms or contiguous farmland.

The design, layout and construction of channel terraces are not within the scope of this Bulletin. Details are available in textbooks on open channel hydraulics and the USDA Soil Conservation Service Engineering Field Manual (36).

6.10 GULLY CONTROL

The causes of gully formation on arable and range lands are discussed in Chapter 3. Obviously the best and most economical policy is to prevent in so far as possible the formation of gullies in the first place by applying soil conservation practices as described previously in this chapter. When large gullies already exist the cost of reclamation may exceed the returns. Under these conditions the best that can be done is to stabilize the gullies and prevent them from getting worse. Small gullies can usually be reclaimed by relatively inexpensive methods.

Run-off from the watershed must be prevented from entering the head of the gully. This can be done by constructing a diversion channel above the top of the gully, or by constructing a series of channel terraces. The diversion channel should discharge into a suitable natural drainage way, or waterway. The location of the diversion channel must be sufficiently far away from the head of the gully so that there is no danger of the diversion channel collapsing into the gully.

Once extraneous run-off has been diverted a large gully can be stabilized and a small one eventually reclaimed by the use of natural or planted vegetation. It may be possible to stabilize or reclaim the gully simply by preventing the entry of livestock. This measure alone may often be sufficient to allow natural regeneration of vegetation. If planting is required trees, shrubs, vines and grasses adaptable to the soil and climate may be used. If the gully is to be employed as a waterway it may be necessary to fill in the sides and shape the bottom by hand or machinery, (Figure 57).

FIGURE 57. - Pushing soil into a gully prior to shaping and seeding for use as a grassed waterway. (Dakota, U.S.A. Photo courtesy of USDA Soil Conservation Service)

Check structures or small dams may be required where it is difficult to establish vegetation or where the slope of the gully channel is steep. Temporary structures may be made of creosoted wood planks, rocks, logs, brush, woven wire, sod or earth, with broadcrested weirs. In the case of large gullies it is often more satisfactory and economical in the long run to use permanent structures made of masonry. These structures must be designed with sufficient hydraulic capacity and have provision for dissipation of the energy of the water flowing over the crest. Design criteria and procedures for these kinds of structures are not within the scope of this Bulletin. An example of trapezoidal weir type structures controlling a gully in Yugoslavia is shown in Figure 58.

FIGURE 58. - Permanent structures controlling a gully. (Yugoslavia: FAO Photo.)

6.11 CONTROL OF DRIFTING SAND AND SAND DUNES

The control of wind erosion depends on the efficacy of the measures used to combat it. The use of vegetative cover, strip cropping (including agro-silviculture) and certain cultural practices have been discussed. The value of maintaining crop residues on the surface of the land or in the top layers of the soil cannot be over-stressed.

However, in areas of very erodible sands and where sand dunes and drifts exist (Figure 59) special measures may be necessary.

FIGURE 59. - Wind erosion on unprotected farm land resulting in drifting sand and sand dunes. (Colarado, U.S.A. Photo courtesy of USDA Soil Conservation Service)

The main need is to establish vegetation. This may necessitate the use of mechanical barriers followed by agronomic measures. Fertilizers may be helpful, particularly organic fertilizers if available. Soils with a high sodium content may need the application of gypsum to improve structure and infiltration of water. Special salt tolerant plant species need to be used in saline areas.

It is often necessary to first level off major humps and dune crests before grasses are planted. The most successful way to establish vegetation by seeding is to apply a heavy cover of mulch at the time of seeding. The mulch will generally have to be anchored to prevent it being blown away. These operations should be done when there is rainfall and when wind velocity is at its lowest. Species of grasses, shrubs and trees used in dune and sand drift stabilization should be adapted to the local conditions.

Examples of this kind of work in progress in Chile are shown in Figures 60 to 62. The nursery shown in Figure 60 is being used to multiply various species for planting out, including in this case Halaxylon persicum, Tamarix, Sualda and Calligonum.

FIGURE 60. - Multiplication nursery for plants suitable for stabilization of sand drifts and dunes. (Chile: FAO Photo by H. Hull)

Figure 61 shows the establishment of Lupinus arboreus ("cho-che") on loose sandy soil. Figure 62 shows a method of planting drought resistant grasses for the stabilization of sand dunes.

FIGURE 61. - Establishment of Lupinus arboreus ("cho-che") on loose sandy soil. (Chile: FAO photo by H. Hull)

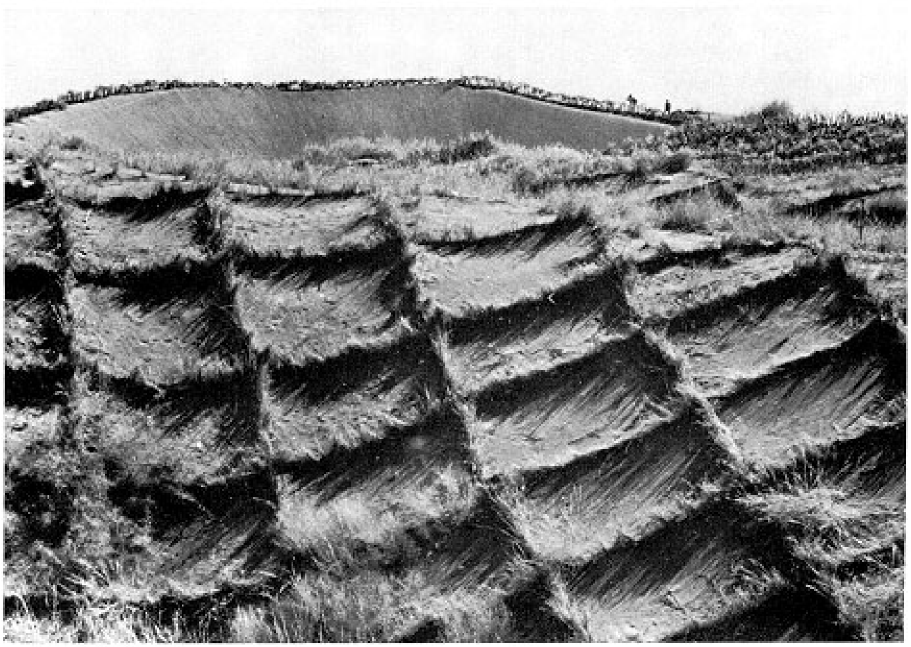

FIGURE 62. - Stabilization of sand dunes. (Chile: FAO photo by H. Hull)

LIST OF REFERENCES

1. Bennett, 1939 — H.B. Soil Conservation. McGraw-Hill Book Company, Inc. New York & London.

2. Tanzania, 1956/61 — Ministry of Agriculture, Forestry and Wild Life. Annual reports of agricultural research stations - maize.

3. Tanzania, 1954/55 — Ministry of Agriculture, Forestry and Wild Life. Annual reports of agricultural research stations - cotton.

4. Charreau, C. 1974 — Organic matter and biochemical properties of soil in the dry tropical zone of West Africa. Soils Bulletin No. 27, FAO, Rome.

5. Hudson, N. 1971 — Soil conservation. B. T. Batsford Ltd., London.

6. Rapp, A., 1972 — Axelsson, V., Berry, L., and Murray-Rust, D.H. Soil erosion and sediment transport in the Morogóro river catchment, Tanzania. Uppsala.

7. FAO. 1973 — Man's influence on the hydrological cycle. Irrigation and Drainage Paper, Special issue, No. 17. FAO, Rome.

8. FAO. 1965 — Erosion by water. FAO Agricultural Development Paper, No. 81. FAO, Rome.

9. Temple, H. and Rapp, A. 1971 — Land slides in the Mgeta Area, Western Uluguru Mountains, Tanzania.

10. Oldfield, F. 1960 — Late Quaternary changes in climate, vegetation and sea level in Lowland Lonsdale. Trans. Inst. of British Geographers. No. 28.

11. FAO. 1974 — Report of FAO/SIDA/ARCN Regional Seminar on Shifting Cultivation and Soil Conservation in Africa: FAO/SIDA/TF 109. FAO, Rome.

LIST OF REFERENCES
(Cont'd)

12. Agboola, A.A., Obigbesan, G.O., and Fayemi, A.A.A. 1974 Interrelations between organic and mineral fertilizers. Paper presented at the FAO/SIDA Expert Consultation on Organic Materials as Fertilizers in December 1974.

13. Parr, J.F. 1974 Chemical and biochemical considerations for maximizing the efficiency of fertilizer nitrogen. Soils Bulletin No. 27, FAO, Rome.

14. King, K.F.S. 1968 Agri-silviculture (The Taungya System), Bull. No.1, Dept. of For., Univ. of Ibadan.

15. Barbe Baker, R. St. 1928 Silviculture experiments at Sapoba, Nigeria. Emp. For. Jour. 7: 203-208.

16. Adetogun, S.A. 1970 The economics of Taungya plantations. Proceedings of First Annual Conference, For. Ass. of Nigeria, Ibadan.

17. Klingebiel, A.A., and Montgomery, P.H. 1966 Land capability classification. Agriculture Handbook No.210, S.C.S., U.S. Dept. of Agriculture.

18. FAO. 1972 Background document; Expert Consultation on Land Evaluation for Rural Purposes. FAO, Rome.

19. Beek, K.J., and Bennema, J. 1972 Land evaluation for agricultural land use planning; an ecological methodology. Landbouw Hogeschool, Wageningen. FAO doc.8B 22.

20. Rapp, A., Berry, L., and Temple, P. 1972 Studies of soil erosion and sedimentation in Tanzania. University of Dar-es-Salaam and University of Uppsala.

21. FAO. 1971 Legislative principles of soil conservation. Soils Bulletin No. 15 by Christy, L.C. and Soil Resources Development and Conservation Service. Land and Water Development Division. FAO, Rome.

22. Moldenhauer, W.C., Wischmeier, W.H., and Parker, 1967 D.T. The influence of crop management on run-off, erosion and soil properties of a Marshall silty clay loam. Proc. Soil Sci. Soc. Amer.

23. FAO. Indigenous and improved farm implements and 1962 machinery for peasant farmers in the Tropics, by I. Constantinesco.

24. Dudley Stamp, L. Contribution to Nature 141 1938 p.268.

25. Faulkner, O.T. Experiments on ridged culti- 1944 vation in Tanganyika and Nigeria. Trop. Agri. (Trinidad) 21, p. 177.

26. Peat, J.E. and Prentice, A.N. The maintenance 1949 of soil productivity in Sukumuland and adjacent areas, Tanganyika, East African Agric. Journal 15, p.48.

27. FAO 1964 Report of the UNSF Project - Agricultural Investigations in Central Tunisia. FAO Rome.

28. King, H.E. et al, Crop physiology - Progress 1960 report from the Expt. Stns. Empire Cotton Growing Corp. 1958-59 Northern Nigeria, p.6.

29. Lawes, D.A. Rainfall conservation and the 1961 yield of cotton in Northern Nigeria. Emp. Journal of Exp. Agric. 27 (116) p.307.

30. McCartney, J.C. A system of cultivation 1964 developed for areas of marginal rain- fall. M.Sc. Thesis, Queens University, Belfast.

31. Farbrother, H.G. Developments in farm 1960 mechanization at Namulonge. Empire Cotton Growing Rev. 37 (4) p.274.

32. FAO. Equipment and methods for tied ridge
1966 cultivation. Farm Power and Machinery. Informal Working Bulletin 28. FAO, Rome.

33. Cashmore, W.H. and Hawkins, J.C. Tillage
1957 equipment and soil conservation. Journal Inst. of Agric. Engineers, No.1, Vol. X111.

34. U.S. Soil Conservation Service. Technical
1951 specifications for conservation practices, Upper Missouri Valley, Reg. 3. Milwaukee.

35. Ramser, C.E. Run-off from small agricultural
1927 areas. Journal of Agricultural Research 34, (9): 797-823.

36. USDA Soil Conservation Service: Engineering
1969 Field Manual.

37. Chow, Ven Te. Open Channel Hydraulics,
1959 McGraw-Hill Book Company, London.

38. FAO. FAO/UNDP project - Upland Development
1974 and Watershed Management. AGL: DP/ROK/67/522. FAO, Rome.

39. Frevert, R.K., Schwab, G.O., Edminster, T.W.
1955 and Barnes, K.K. Soil and Water Conservation Engineering. John Wiley & Sons. Inc., New York.

40. FAO. Soil Conservation. An International Study.
1952 FAO Agricultural Study No. 4. FAO, Rome.

41. FAO. Soil erosion by wind and measures for its
1960 control on agricultural lands. FAO Agricultural Development Paper, No.71. FAO, Rome.

42. Wischmeir, W.H., Erosion and Sedimentation.
1974 Proceedings of 29th Annual Meeting of SCSA.