# Soil Conservation

## Second Edition

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# Chapter 1 Man and soil erosion

## 1.1 THE RELATION BETWEEN MAN AND THE EARTH'S RESOURCES

The balance between the demands which a community of plants or animals makes on its environment and the ability of nature to satisfy those demands is not the static equilibrium of a laboratory scale with equal weights on either side. It is more like the unstable balancing of a circus acrobat—a series of swings and overcorrections, resulting in an oscillation on either side of the true balance point. Thus a species of wild life increases in number according to the availability of its food supplies, but then goes beyond the optimum number. The natural correcting factors of starvation or migration reduce the population, but again there is an overcorrection, and soon the cycle starts again with increasing numbers.

### 1.1.1 The Malthusian Thesis

In primitive societies the human population also oscillates about a mean as the limiting factors of starvation, disease, and war, maintain an uneasy balance against the natural tendency to increase. A serious imbalance arises when man learns how to modify the limiting factors, but allows the natural increase to go unchecked. The essence of the *Malthusian Thesis* is that the resulting instability is the inevitable order for mankind. The thesis is named after the English political economist Thomas Malthus who first gave it formal expression (McCleary 1953). In an age when significant improvements in health, hygiene, and the standard of living were just becoming possible, Malthus aroused great argument when he pointed out that these very improvements could lead to misery through overpopulation. One of the key points in the argument is that populations tend to increase exponentially (1, 2, 4, 8, 16) while the supply of food and other essential requirements normally tends to increase arithmetically (1, 2, 3, 4, 5). In the last century the opening up of extensive areas of the unexplored world disguised the normal growth rate, and at a time when it appeared that the supply of new lands was inexhaustible, Malthus's ideas did not seem very relevant. Today it is clear that the world population is indeed increasing rapidly, and will continue to do so even if the growth rate declines from the rate of the last twenty years. Also the increase is greatest in the developing countries. Europe in the last century saw major changes with the diversion of labour from agriculture to industry, and a corresponding movement from country to town, accompanied by a rapid increase in population (figure 1.1). This pattern is now appearing in many developing countries.

It is worth considering briefly the main causes of this increase. First, and probably the most important, are improvements in health and hygiene. Diseases which used to act as checks on the population of under-developed countries are being controlled. For example, in the case of malaria, the knowledge of how mosquitos spread the disease, together with new prophylactic drugs and the application of techniques such as aerial spraying, have reduced it from a scourge to little more than an inconvenience. Secondly, the spread of education and the teaching of simple rules of hygiene have greatly diminished incidence of diseases such as dysentery, hookworm, and bilharziasis. A third cause is that starvation is greatly reduced. Not that millions of people in the world are not hungry—they are, and the number increases daily (EHRLICK 1972)—but international famine relief schemes, and the ability to move large quantities of food to famine areas, mean that populations are less frequently decimated by starvation than they have been in the past. (DANDO 1980).

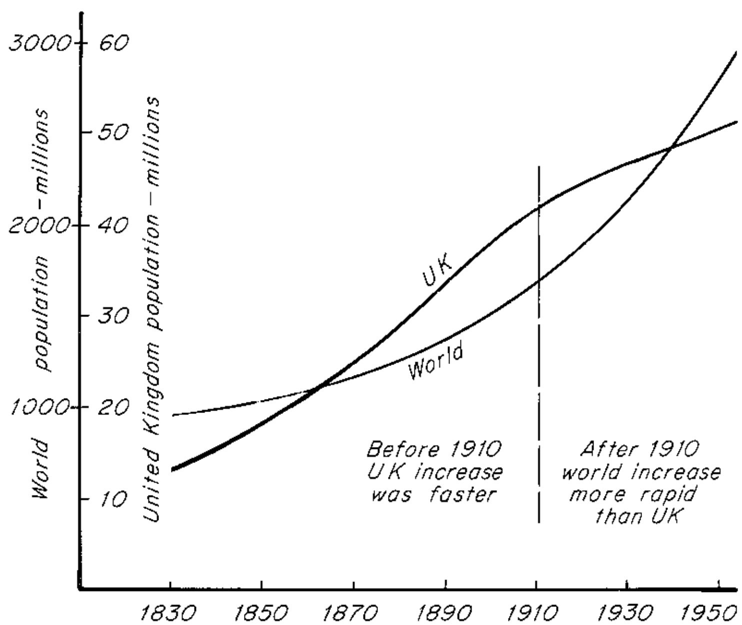



FIGURE 1.1 *Rates of increase in population*

Apart from these reductions in the factors which limit population increase, there are other influences positively helping the increase. Malthus recognized that when more jobs are available there will always be more people to fill them as surely, though not so directly, as better food supplies lead to more people to consume the food. The developing countries today have both increasing food supplies and increasing labour outlets. There is also another factor which did not occur in Malthus's time. This is the effect of aid from more affluent nations, which may have the side effect of stimulating population growth.



## 1.1.2 The exploitation of resources

The tremendous increase in the population of the world is well documented, and debate now centres on whether the growth rate is declining significantly as a result of birth control programmes (GILLAND 1979). The more important issue is whether the natural resources of the world are able to feed, clothe, and provide for the present and future population. There is a wide range of opinion on this. The optimists believe that the potential for increase in food supplies is ample for forseeable needs (REVELLE 1976), or that the problems are overexaggerated (MADDOX 1972). The pessimists, nicknamed the Doomsters, who are the stronger voice in current debate, believe that the demands on the resource base cannot be supplied indefinitely (MEADOWS *et al* 1972, ECKHOLM 1976, BROWN 1978). Figure 1.2 is a simplified example from the simulation model explored in *Limits to Growth* which suggests that whichever of the possible projections actually takes place, the world's resources will be inadequate. For countless centuries the world's capital of natural resources, the minerals, the forests, and the soil, was only required to yield a very modest interest which was sufficient to provide for man's requirements. As the population grew, it became necessary first to extract ever increasing interest, and then to start using up the capital resources.

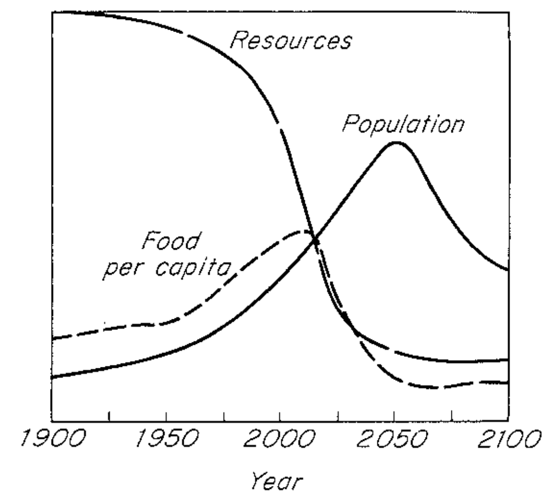



FIGURE 1.2 *Computer simulation models attempt to predict the effect of possible changes. This is the prediction of what would happen if there are no changes in present trends of population, food production, pollution and so on. Adapted from* MEADOWS *et al 1972*

In the latter half of the previous century and the first half of this, the industrial revolution and mechanization of agriculture gave impetus to the population expansion and also put into man's hand the tools, the machines, and the engines, which made possible the exploitation of natural resources on a scale previously unimagined. This exploitation of non-renewable resources still continues. The large scale export of cereals from North America, or beef from South America, or dairy products from New Zealand, are all non-sustainable exploitation of land resource capital, achieved only by the using up of fertility, and accompanied by a decrease in the long-term productivity of the land.

In the second half of this century another threat has emerged—the increasing pressure on the land caused by the growing population. The unwise use of marginal land is increasing, for example, the upward spread of cultivation into steep land better left as forest is a growing problem in the Himalayas, the Andes, and the mountain regions of many countries in the humid tropics. The apparent inability of present social and political organisations to solve this problem is discussed in Chapter 16.

The debate will continue on the balance between resources and demand, but some issues are beyond doubt. The world population is increasing and will continue to do so, with an increasing need which will be difficult to meet. A recent FAO analysis suggests that 'it would appear that the 200 million hectares of additional land estimated to be required to produce sufficient food for the world population by the year 2000 would just compensate for soil loss and would therefore not add to agricultural production' (DUDAL 1981). In this situation we cannot afford to allow the land resource base to be damaged by soil erosion.

This analysis of the significance of soil erosion is not new. The extent of the erosion damage was very clearly stated more than 40 years ago by JACKS and WHYTE (1939), and their conclusions have been confirmed and reinforced on many occasions since (VOGT 1948, HELD and CLAWSON 1965, CARTER and DALE 1974).

Hard facts on the amount of damage by erosion are scarce, and one of the most reliable (and dramatic) surveys is still that carried out in the United States of America in 1934, which showed that out of a total of 167 million hectares (414 million acres) of arable land

20 million hectares were ruined, (50 million acres) 12%
20 million hectares were almost ruined, (50 million acres) 12%
40 million hectares had lost more than half the topsoil, (100 million acres) 25%
40 million hectares had lost more than a quarter of the topsoil, (100 million acres) (BENNETT 1939). 25%

In other words, nearly 75% was seriously damaged. There is little doubt that equally devastating results would emerge from surveys in most countries of the world where agricultural development has been recent.

Production per hectare should have increased dramatically in the last thirty years as a result of the introduction of improved crop management, better seed, better tillage implements, and increased use of fertilizers. In fact, the benefits of these have been so much offset by the decline in fertility due to erosion that the increase in national average yield of several crops has been disappointing (SHRADER 1975).



Today, many countries have Soil Conservation services and conservation programmes, but the unfortunate truth is that, even in those countries which are making the most strenuous efforts, the result is only a slowing down of the rate of destruction of the soil. The total wastage on a world scale is worse than ever. Two reasons may account for the lack of progress. First, the restrictions on soil exploitation are socially and politically unacceptable to people and to governments when such exploitation is adding to the immediate prosperity of individuals and of the nation. Secondly, in a hungry world it is hard to restrict the provision of badly needed food even if this does mean the reduction of long-term productivity. This problem is further explored in Chapter 16.

## 1.2 THE POSSIBILITIES OF INCREASING FOOD PRODUCTION

Food production could be increased by:

(*a*) increasing the area of cultivated land
(*b*) increasing the yield
(*c*) Developing new food sources

### 1.2.1 Increasing area

The area of land now under cultivation is estimated to be 1500 million hectares, but how much this could be increased is uncertain as estimates of the potential arable land range from 0·9 billion hectares (BOERMA 1975) to 9·0 billion (PAWLEY 1971). But development to date has naturally been on the best and easiest land. That now remaining includes areas of dense forest, of desert, regions where development is unlikely until health hazards like malaria or trypanosomiasis have been cleared up, and areas presently unpopulated. Furthermore, the development of new land would tend to be unevenly distributed, for there is little land available for new development in those countries with the worst problem of overpopulation and underfeeding.

### 1.2.2 Increasing yields

Here is the greatest opportunity. The average yield of maize in many parts of Africa is below 1000 kilos of grain per hectare, while experimental stations consistently demonstrate that yields twice or three times greater can be achieved by applying elementary techniques, and intensive production can give 8000 kg/hectare. Similarly, much of the world's rice is produced at yields only a fifth or a quarter of those which could be obtained. In order to achieve increased yields, the primary requirement is not research into new methods, but the increased application of techniques and practices which are already known. Other requirements are improved strains, more research into local conditions, more use of fertilizers, more capital, more mechanization, and the reduction of wastage from pest and disease. But the immediate problem is to double the yield of peasant agriculture by the application of elementary agronomy. Theoretically, this should be simple.

The FAO project to assess the potential production of specific crops by computerised analysis of the soil and climate has shown that substantial increases are theoretically possible in some regions (FAO 1978) but from the evidence available it appears to be more difficult to increase production in the Third World than to raise even higher the level of productivity in the highly developed and capitalized agriculture of the USA and Europe. The problems of implementing new practices are discussed in Chapter 16.

### 1.2.3 Other sources of food

Man is a resourceful creature, particularly when his survival is threatened, and there is a strong possibility that hitherto untapped sources of food will be sought out and developed. The chemical food pill of science-fiction writers is still impractical, but three possible sources, all being seriously investigated today, are the large-scale exploitation of fish foods, the processing of lower forms of marine life, such as algae and plankton, and the manufacture of synthetic protein.

Fish, when produced in artificial ponds as a crop which is established, grown, and harvested, can give a higher yield in terms of kilograms per hectare than an irrigated vegetable crop, and further provide the animal protein which is the main deficiency in the diet of most underfed people. In natural streams, rivers, and lakes, 'fish farming' cannot be as precise as in artificial ponds, and the yields are correspondingly lower, but the inland waters of the world could yield much more than the 2% of the world's edible fish which they presently supply.

It is estimated that the oceans of the world could provide a maximum sustainable yield of about 118 million tons live weight of fish, compared with present yields of about 75 million tons (FAO 1976). However, there is a danger of the long-term productivity being damaged by overfishing (EHRLICH 1972 p. 125–134) in the same way that the soil resource can be damaged by excessive exploitation.

The idea of algae or plankton as a food is not attractive at present, but the growth of such forms of life is a highly efficient way of converting chemical nutrients and the sun's energy into edible substances, and the product might be made palatable in either of two ways: by treatment, including the addition of synthetic tastes, so that the origin was not recognizable, or by using it as a high-quality food for conventional food animals like pigs, poultry, or cattle.

The manufacture of synthetic protein is at an early stage of development, but biotechnology is one of today's growth industries and rapid progress is likely. The two main approaches are single cell micro-organisms converting petroleum products, and yeast fermentation of inedible crop residues like straw. It is probable that, like algae, the product will be used as a feed for livestock or fish rather than for direct



human consumption. The present position appears to be that there are limited opportunities for expanding conventional food supplies, and unproved opportunities for developing new supplies, but the enormous gulf between supply and demand focuses attention on the vital need to prevent any running down of the soil's productivity.

## 1.3 THE HISTORICAL BACKGROUND OF SOIL EROSION

Today soil erosion is almost universally recognized as a serious threat to man's well-being, if not to his very existence, and this is shown by the fact that most governments outside Europe give active support to programmes of soil conservation. But it is relevant, before making any assessment of present knowledge of erosion, to consider the development of this science which was almost unknown 80 years ago, and now enjoys world-wide attention.

Studies of the effect of erosion on early civilizations have shown that a major cause of the downfall of many flourishing empires was soil degradation (LOWDERMILK 1953). Although this is clearly evident throughout 7 000 years of history, an awareness of the problem developed very slowly.

There are passing references in the Old Testament, mainly threats of streams drying up. Occasionally Greek writers mention the problem eg Homer on fallows, Plato on floods and deforestation. The Romans had a slightly better understanding, with Virgil advocating what today we would call conservation farming, but the main point is that it was not until the beginning of the present century that an appreciation of the problem was sufficiently widespread for governments to start taking an interest.

Part of this reluctance to appreciate the significance of erosion may stem from the fact that the earliest civilizations all arose on irrigated alluvial plains, and were frequently dependent upon flood deposits of silt for continued fertility. The civilizations of the valleys of the Nile, the Tigris, and the Euphrates, which owed their existence to erosion in the headwaters, could hardly be expected to see erosion in the same light as a modern agricultural community.

There is some debate about whether long term changes in climate have affected past soil degradation. The conventional view was that no climatic change has occurred (REIFENBERG 1955), but more recently VITA-FINZI (1969) has shown that major geological changes have taken place in the Mediterranean in historical times, and PARRY (1978) suggests that climatic changes may have been more important than was previously assumed. However, the evidence of protected temple forests in both China and the Lebanon suggests that whether or not climate has been a contributing factor, the devastation we see today is essentially a man-made phenomena.

## 1.4 THE GROWTH OF EROSION RESEARCH

The first scientific investigations of erosion were carried out by the German soil scientist WOLLNY, between 1877 and 1895. Small plots were used to measure a wide range of effects, such as that of vegetation and surface mulches on the interception of rainfall and on the deterioration of soil structure, and the effects of soil type and slope on run-off and erosion. Apart from this pioneer work, the lead in erosion research has come mainly from the United States of America. Isolated cases of practical application by farmers of mechanical conservation works increased from the 1850s until, in 1907, the United States Department of Agriculture declared an official policy of land protection.

The first American quantitative experiments were laid down by the Forest Service in 1915 in Utah, closely followed by those of MILLER in Missouri in 1917, which led in 1923 to the first published results of field plot experiments. Other similar experiments followed, using essentially the same method, and were given added impetus by the allocation of funds by Congress in 1928. These enabled BENNETT to establish between 1928 and 1933 a network of ten field experiment stations. During the next decade this programme expanded until forty-four stations were operating, and included experiments on mechanical erosion control and run-off from small catchments.

Throughout this period the work was limited to applied research, in which problems were studied under field conditions; and, although it had been apparent from the earliest days of Wollny's work that the prevention of splash erosion was of vital importance, there was no coordinated research involving an analytical study of the processes of erosion. Pioneer work in this field was carried out in the 1930s by a few individuals such as BAVER, BORST, WOODBURN, and MUSGRAVE, and led to the first detailed study of natural rain by LAWS in 1940, and the first analysis of the mechanical action of raindrops on the soil by ELLISON in 1944. The implications of this are best described by STALLINGS (1957 Chapter 1) who says:

'The discovery that raindrop splash is a major factor in the water erosion process marks the end of one era in man's struggle with soil erosion and ushers in another which, for the first time, holds out hope for a successful solution to the problem. The exact nature of the effects of raindrop splash is the phase of the water-erosion process that escaped detection during the first 7000 years of civilization. It explains why the efforts at protecting the land against scour erosion these 7000 years have failed. It explains why there is little or no erosion on land with ample plant cover. It explains many things that have puzzled agricultural leaders and practitioners throughout this long and troublesome period. . . .

It remained for Ellison to recognize the true role of the falling raindrop in the water erosion process. He was the first to realize that the falling raindrop was a complete erosive agent within itself and that little or no erosion occurred when the ground surface was protected by ample cover. He showed that the protective effect of plant cover was due to the fact that it robbed the falling raindrop of its kinetic energy. Ellison's discovery opened a new field of soil erosion science.'



Analytical research was directed to more specific objectives by the setting up in 1954 of a national study, which used modern techniques of data analysis to correlate the results of all the field experiments (WISCHMEIER 1955). As a result of this study, the main features in the erosion process were identified and mathematically enumerated. (WISCHMEIER *et al* 1958). This work ushered in the phase of quantitative scientific investigation discussed in subsequent chapters.

The United States has always maintained a commanding lead, both in research on the erosion process and in studies of the application of conservation practices. Many other countries have followed with national programmes designed to test the relevance of US work in other conditions, particularly in tropical countries where erosion is particularly severe. National programmes have been reinforced by international programmes. A notable example was SARCCUS (South African Regional Commission for Conservation and Utilisation of the Soil) which pioneered this approach 30 years ago (ROWLAND 1974). More recently the international agencies like FAO, UNEP, and UNESCO have become involved in action programmes, and the international agricultural research stations have started multi-national research on erosion, particularly ICRISAT in India, and IITA in Nigeria.

## 1.5 THE GEOGRAPHICAL DISTRIBUTION OF EROSION

The two main agents of erosion are wind and water, and by consideration of the conditions under which each will be active, a pattern can be built up of the areas of the world where either wind erosion or water erosion is likely to be particularly serious.

### 1.5.1 Erosion by water

The factor which most influences soil erosion by water is the mean annual rainfall, as shown in figure 1.3. In regions of very low rainfall there can naturally be little erosion caused by rain. Further, what little rain does fall is mainly taken up by a vegetation permanently short of water so there is little run-off. At the other extreme, an annual rainfall of more than 1000 mm usually leads to dense forest vegetation. This affords protective cover to the soil and, as is shown in the next chapter, the presence of cover is the key factor in reducing water erosion. The most severe erosion will thus tend to be associated with the middle range of rainfall when the vegetation is largely undisturbed, and with higher rainfall when the natural forest is removed. The main features of world rainfall distribution are shown in figure 1.4.

However, it is not only the *amount* of rainfall that matters, but also the *kind* of rain. The intensive downpour common in the tropics has a very

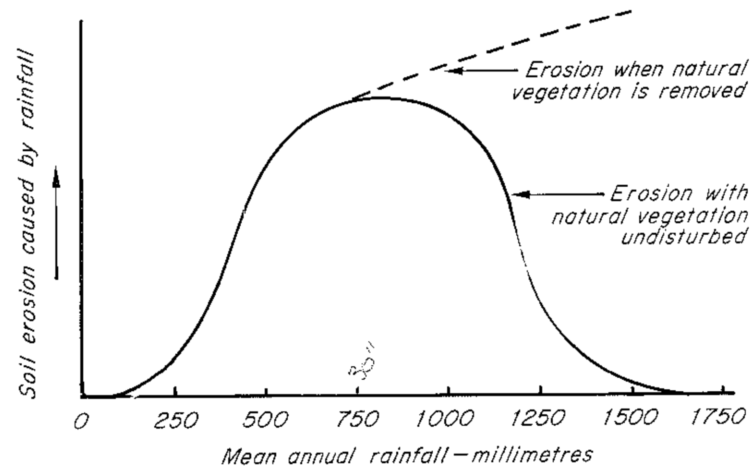



FIGURE 1.3 *The relation between rainfall and soil erosion*

much more damaging effect than the gentler rain of temperate climates, and the approximate limits of the area of destructive rain are latitudes 40° North and 40° South. There are, of course, exceptions to this world-scale pattern. In semi-arid conditions, serious rain erosion often occurs because the rain, although low in quantity, comes in very severe storms (plate 1.1). In other cases, steep slopes and vulnerable soils can lead to quite serious erosion in temperate latitudes. In general, however, soil erosion by water can be expected to be most serious in areas between these latitudes, where the annual rainfall is neither very high nor very low. Figure 1.5 shows that, as a first approximation, this is in fact the case, the main areas being N. America up to about 40° N, parts of S. America, nearly all of Africa except the dry deserts and equatorial forest, Asia up to 40° N, and Australia excluding the dry centre.



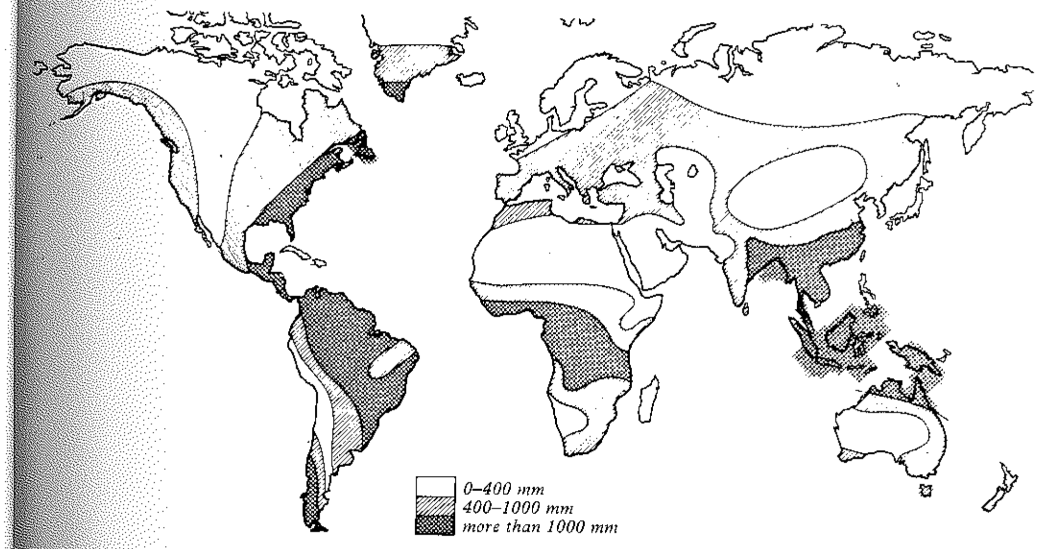



FIGURE 1.4 *Generalized map of mean annual rainfall*

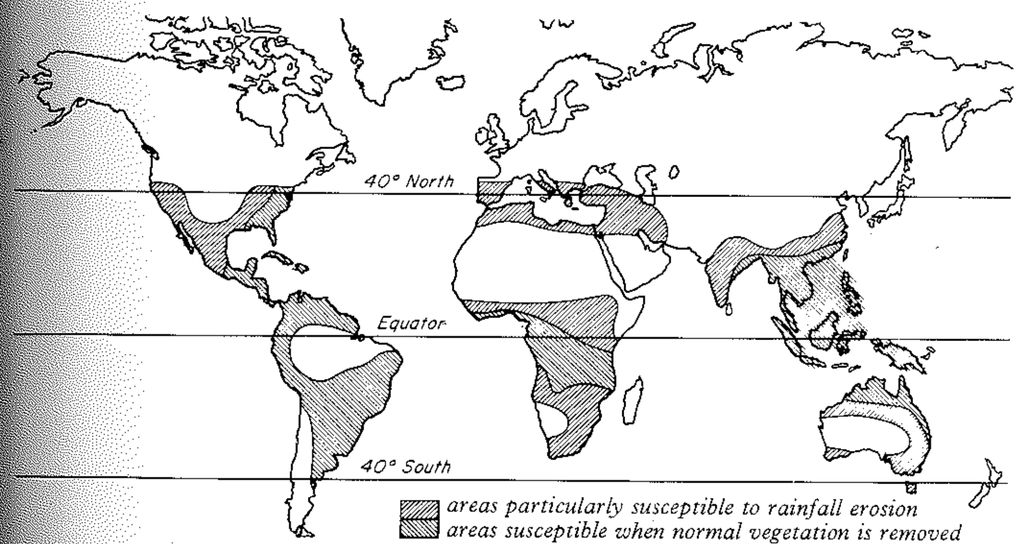



FIGURE 1.5 *Generalized map of the geographical distribution of rainfall erosion*

### 1.5.2 Erosion by wind

There are also two main conditions which must exist before wind erosion can be a serious problem. First, only dry soil blows, so the vulnerable regions are those with a low mean annual rainfall, particularly less than about 250 or 300 mm. Secondly, large-scale movements can occur only where there are steady prevailing winds at all levels from the upper air down to ground level, and these are associated with large, fairly level land masses. Naturally, there exist local exceptions, but on a continental scale, wind erosion is found to be most serious where it would be expected from consideration of these two requirements. The main areas, shown in figure 1.6, are N. America (the Great Plains, famous as the Dust Bowl), the Sahara and the Kalahari deserts in Africa, Central Asia (particularly the Steppes of Russia), and central Australia.

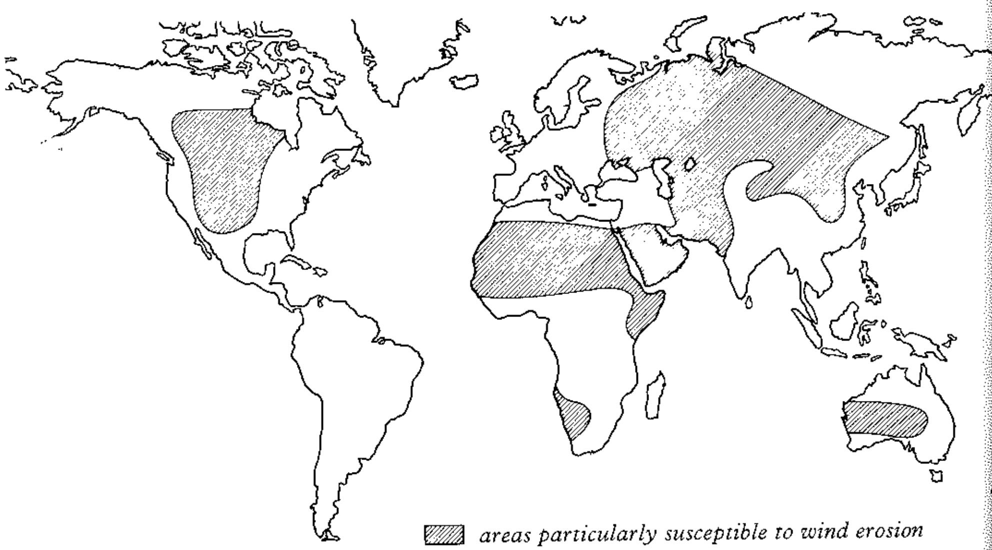
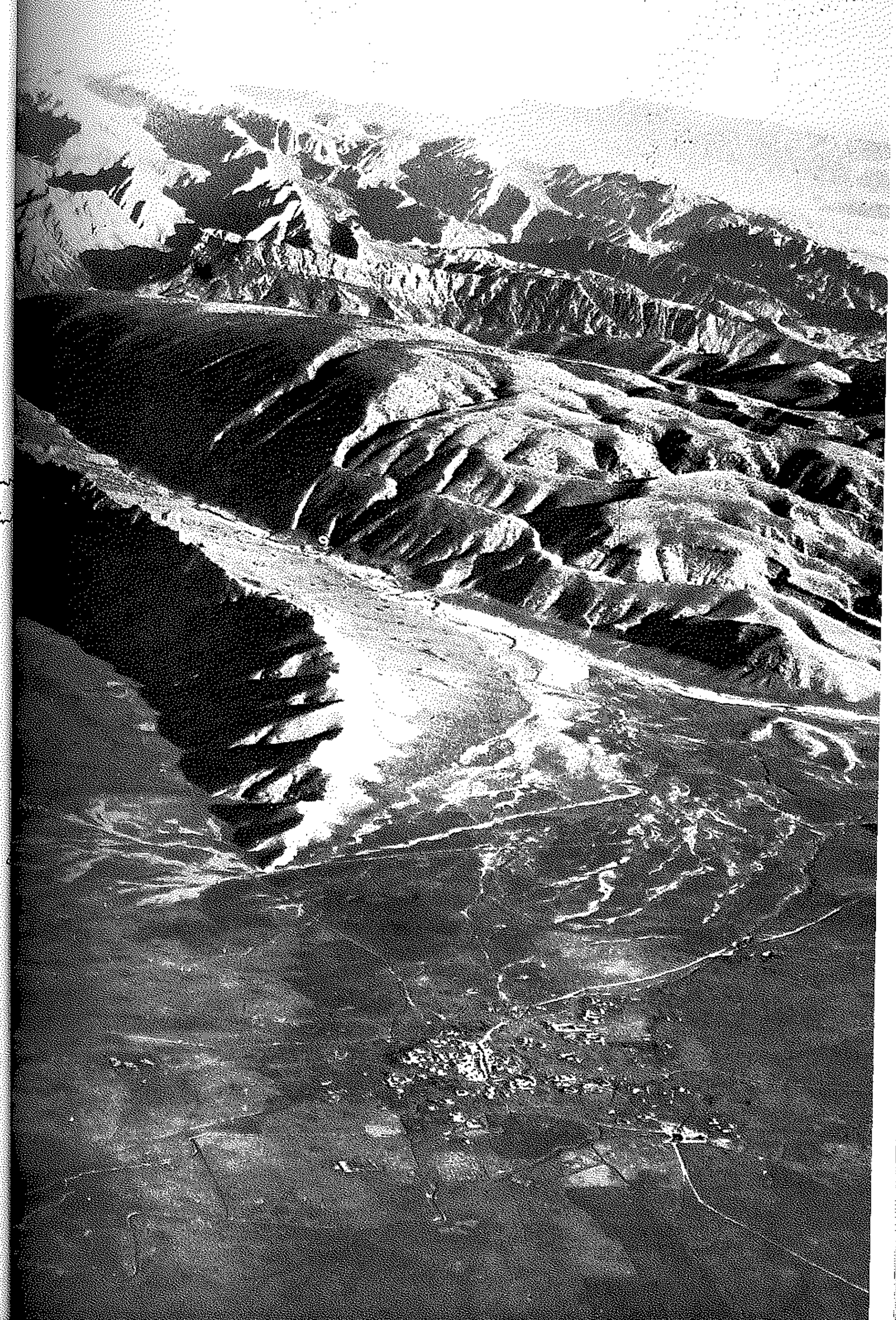



FIGURE 1.6 *Generalized map of wind erosion*

PLATE 1.1 *Rainfall erosion is greatest when heavy rainstorms fall on land unprotected by vegetation* *Copyright Aerofilms Limited*



## References


BENNETT, H. H. 1939 *Soil Conservation*, McGraw-Hill, New York

BOERMA, A. H. 1975 The World Could be Fed, *Journal of Soil and Water Conservation*, 30, 1, 4–9

BROWN, L. R. 1978 *The Twenty Ninth Day*, Worldwatch Institute, Norton, New York

CARTER, V. G. and T. DALE 1974 *Topsoil and Civilisation*, University of Oklahama Press

DANDO, W. A. 1980 *The Geography of Famine*, Edward Arnold, London

DUDAL, R. 1981 An Evaluation of Conservation Needs, in: *Soil Conservation: problems and prospects*, edited by R. P. C. MORGAN, Wiley, Chichester

ECKHOLM, E. P. 1976 *Losing Ground*, Worldwatch Institute, Norton, New York

EHRLICH, P. R. and A. H. EHRLICH, 1972 *Population Resources Environment*, 2nd edition, Freeman, San Francisco

ELLISON, W. D. 1944 Studies of Raindrop Erosion, *Agricultural Engineering*, 25: 131–136, 181–182

FAO, 1976 *Yearbook of Fishery Statistics*, FAO, Rome

FAO, 1978 Report on the Agro-ecological Zones Project. Vol. 1 Methodology and results for Africa. Vol. 2 Results for South West Asia. *World Soil Resources Reports 48 and 48/2*, FAO, Rome

GILLAND, B. 1979 *The Next Seventy Years*, Abacus Press, Tunbridge Wells

HELD, R. B. and M. CLAWSON 1965 *Soil Conservation in Perspective*, Johns Hopkins, Princeton, N.J.

JACKS, G. V. and R. O. WHYTE 1939 *The Rape of the Earth—A world Survey of Soil Erosion*, Faber, London

LAWS, J. O. 1940 Recent Studies in Raindrops and Erosion, *Agricultural Engineering*, 21, 431–433

LOWDERMILK, W. C. 1953 Conquest of the Land Through Seven Thousand Years, *Agricultural Information Bulletin 99, United States Department of Agriculture*

MADDOX, J. 1972 *The Doomsday Syndrome*, Macmillan, London

McCLEARY, G. F. 1953 *The Malthusian Population Theory*, Faber, London

MEADOWS, D. H., D. L. MEADOWS, J. RANDERS and W. W. BEHRENS III 1972 *The Limits to Growth*, Earth Island, London

PARRY, M. L. 1978 *Climatic Change, Agriculture and Settlement*, Dawson and Sons, Folkestone

PAWLEY, W. H. 1971 In the Year 2070, *Ceres*, 4, 4, 22–27

REIFENBERG, A. 1955 *The Struggle Between the Desert and the Sown*, The Jewish Agency, Jerusalem

REVELLE, R. 1976 The Resources Available for Agriculture, *Scientific American*, 235, 1, September, 164–178





ROWLAND, J. W. 1974 *The Conservation Ideal* South African Regional Commission for Conservation and Utilisation of the Soil, Pretoria

SHRADER, W. D. 1975 What is Happening to Our Soil Resources: Losses to Erosion, in: Land Use: Persuasion or Regulation? *Proceedings of 29th Annual Meeting of Soil Conservation Society of America*, August 1974

STALLINGS, J. H. 1957 *Soil Conservation*, Prentice-Hall, Englewood Cliffs, New Jersey

VITA-FINZI, C. 1969 *The Mediterranean Valleys—Geological Changes in Historical Times*, Cambridge University Press

VOGT, W. 1948 *Road to Survival*, Sloane, New York and Gollancz, London

WISCHMEIER, W. H. 1955 Punched Cards Record Run-off and Soil Loss Data, *Agricultural Engineering* 36, 664–666

WISCHMEIER, W. H., D. D. SMITH, and R. E. UHLAND 1958 Evaluation of Factors in the Soil-Loss Equation, *Agricultural Engineering*, 39, 8, 458–462, 474