3 Sloping land: soil erosion problems and soil conservation requirements

D.W. Sanders

Land and Water Development Division FAO, Rome

3.1 Introduction

I have been asked as a Soil Conservationist to discuss sloping land and its implications for soil erosion and conservation. As this paper is being delivered as an introduction to the meeting, I would like to start by discussing three different, fundamental, but closely related aspects of the subject. Firstly, I would like to look into the question of how important sloping land is to us and how important it is going to be in the future; secondly, what are its particular problems in relation to soil erosion and thirdly, what are the practical problems we are now encountering as we try to produce workable land-use plans for sloping land.

As the world’s population increases and the demand for food and other agricultural commodities grows, it is inevitable that more demands will be placed on land which is marginal for agriculture. Much of the world’s marginal land is on medium to steep slopes and is very prone to water erosion. If it is to be developed in a manner which will allow sustainable production, extensive soil conservation measures will have to be applied.

A brief review is made here of our land resources and the demand which will be made on them in the future, particularly on the sloping land. Soil erosion and its control are briefly discussed, while attention is drawn to the very serious problems which we now face with sloping lands in highly populated countries.

3.2 Land resources and the use of sloping land

The world’s present population numbers some 4.5 billion and it is expected to increase to approximately 6.2 billion by the year 2000. Present projections indicate that the world population will eventually stabilize at about 10.5 billion by the year 2110. The bulk of this increase will have been reached by 2055, when there will be 9.3 billion people (Salas, 1981).

Given these increases, the demand for food and other agricultural commodities will increase dramatically in the future: increasing by about 50% by the end of the century and more than doubling present demands by the middle of the next century.

For those involved in planning land use, these figures raise the overriding questions: will there be enough land to meet these needs in the future.

The results of work undertaken by FAO, and based on the FAO/Unesco Soil Map of the World (FAO, 1981), indicate that there is enough land.

The FAO studies estimate that the world’s potentially cultivable land (very suitable, suitable and marginally suitable) amounts to just over 3 billion hectares or about 22 per cent of the earth’s total land area. Of this, about half is at present in use.
Table 3.1 Land use and population.

<table>
<thead>
<tr>
<th></th>
<th>Developing Countries</th>
<th>Developed Countries</th>
<th>Total World</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land area (million ha)</td>
<td>7,619</td>
<td>5,773</td>
<td>13,392</td>
</tr>
<tr>
<td>Percent of world’s total</td>
<td>(57)</td>
<td>(43)</td>
<td></td>
</tr>
<tr>
<td>Population, 1979 (millions)</td>
<td>3,117</td>
<td>1,218</td>
<td>4,335</td>
</tr>
<tr>
<td>Percent of world’s total</td>
<td>(72)</td>
<td>(28)</td>
<td></td>
</tr>
<tr>
<td>Potentially cultivable (million ha)</td>
<td>2,154</td>
<td>877</td>
<td>3,031</td>
</tr>
<tr>
<td>Percent of land area</td>
<td>(28)</td>
<td>(15)</td>
<td>(22)</td>
</tr>
<tr>
<td>Percent of world’s potential</td>
<td>(71)</td>
<td>(29)</td>
<td>(100)</td>
</tr>
<tr>
<td>Presently cultivated (million ha)</td>
<td>784</td>
<td>677</td>
<td>1,461</td>
</tr>
<tr>
<td>Percent of potential</td>
<td>(36)</td>
<td>(77)</td>
<td>(48)</td>
</tr>
<tr>
<td>Percent of world’s total</td>
<td>(54)</td>
<td>(46)</td>
<td>(100)</td>
</tr>
<tr>
<td>Persons per ha presently cultivated</td>
<td>4.0</td>
<td>1.8</td>
<td>3.0</td>
</tr>
</tbody>
</table>

Source: Dudal, 1982 – Land Degradation in a World Perspective

The distribution of the potentially cultivable land between developing and developed countries is 71 and 29 per cent respectively, practically in the same proportions as their share of the world population. However, within this overall picture, there are vast differences in resource endowment and use. FAO’s study ‘Agriculture: towards 2000’ revealed that by 1975, 18 of the 90 developing countries reviewed were already reaching the limit of their cultivable land. In addition, the remaining land reserves lie mostly in humid parts of Africa and South America where there are particular management problems.

In South-east Asia, 92 per cent of the available land is already in use, while in South-west Asia more land is being used than is considered suitable for cultivation.

Table 3.2 Land use and population in developing countries.

<table>
<thead>
<tr>
<th></th>
<th>Africa</th>
<th>Southwest Asia</th>
<th>Southeast Asia</th>
<th>Central Asia</th>
<th>South America</th>
<th>Central America</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land area (million ha)</td>
<td>2,886</td>
<td>677</td>
<td>897</td>
<td>1,116</td>
<td>1,770</td>
<td>272</td>
</tr>
<tr>
<td>% of world’s total</td>
<td>(21)</td>
<td>(5)</td>
<td>(6)</td>
<td>(8)</td>
<td>(13)</td>
<td>(2)</td>
</tr>
<tr>
<td>Pop. 1979 (millions)</td>
<td>427</td>
<td>153</td>
<td>1,232</td>
<td>947</td>
<td>239</td>
<td>119</td>
</tr>
<tr>
<td>% of world’s total</td>
<td>(10)</td>
<td>(3)</td>
<td>(28)</td>
<td>(22)</td>
<td>(6)</td>
<td>(3)</td>
</tr>
<tr>
<td>Potentially cultivable (million hectares)</td>
<td>789</td>
<td>48</td>
<td>297</td>
<td>127</td>
<td>819</td>
<td>75</td>
</tr>
<tr>
<td>% of land area</td>
<td>(27)</td>
<td>(7)</td>
<td>(33)</td>
<td>(11)</td>
<td>(46)</td>
<td>(27)</td>
</tr>
<tr>
<td>% of world’s total</td>
<td>(26)</td>
<td>(2)</td>
<td>(10)</td>
<td>(4)</td>
<td>(27)</td>
<td>(3)</td>
</tr>
<tr>
<td>Presently cultivated (million hectares)</td>
<td>168</td>
<td>69</td>
<td>274</td>
<td>113</td>
<td>124</td>
<td>36</td>
</tr>
<tr>
<td>% of potential</td>
<td>(21)</td>
<td>(144)</td>
<td>(92)</td>
<td>(89)</td>
<td>(15)</td>
<td>(49)</td>
</tr>
<tr>
<td>% irrigated</td>
<td>(4)</td>
<td>(16)</td>
<td>(24)</td>
<td>(44)</td>
<td>(6)</td>
<td>(18)</td>
</tr>
<tr>
<td>Persons per hectare presently cultivated</td>
<td>2.5</td>
<td>2.2</td>
<td>4.5</td>
<td>8.4</td>
<td>1.9</td>
<td>3.3</td>
</tr>
</tbody>
</table>

Source: Dudal, 1982 – Land Degradation in a World Perspective.
Another important factor is that large areas of land at present under cultivation are suffering from various forms of land degradation, particularly soil erosion. Very little reliable data are available on the overall extent of this erosion. FAO has estimated that between 5 and 7 million hectares of land are at present being lost annually through soil degradation (FAO, 1981). If this is so, it is reasonable to assume that a much larger area is annually declining in its productive potential. Thus, some areas which were previously suitable for cultivation are now only suitable for grazing, and areas previously suitable for grazing may now only be suitable for low productive forestry.

It must also be borne in mind that most of the land so far brought into production is on the flatter areas, on the deeper, more fertile and easy to work soils. For obvious reasons, farmers have avoided as far as possible the steep lands and the harder to work, shallow, erosion-prone areas.

The picture to emerge from this background is as follows:
Globally, there is potentially enough cultivable land available to meet our foreseeable future demands for food and other agricultural commodities if all the available cultivable land is brought into stable forms of production and yields are increased on at least some of the land which is already under production.

If this were done, and there was free movement of food and agricultural commodities between regions and countries, there would be no need for concern about the world’s future ability to meet its requirements.

However, the movement of food and commodities is, and is likely to remain, restricted for economic and political reasons. We also know that the distribution of cultivable land – both already in use and potentially usable – is very unevenly distributed between countries.

In addition to this, many of those countries where the need to increase agricultural production is greatest are already very short of land, while much land that is in use is seriously eroding and declining in productivity. To make problems worse, much of the potential land left for cultivation is of poor fertility and on steep, erosion-prone slopes.

What then is likely to be the trend in the future and how will it affect those involved in land-use planning?

Large areas of new land will be developed over the next eighty years. As the tendency has been to develop the more fertile, flatter land first, agriculture can be expected to move to the steeper slopes with the poorer, more erosion-prone soils. This movement will not be progressive as land resources are unevenly distributed and most of the densely populated countries now only have the poorer and steeper land left to develop.

Already, people in such countries as Nepal, Ethiopia, Rwanda, Lesotho, Jamaica and many others, are attempting to cultivate large areas of steeply sloping land which by all normal standards could not be considered suitable for cultivation.

The problems of these areas are great, particularly those of soil erosion by water, so that it will become increasingly important for land-use planners to have a sound understanding of why erosion occurs, how to assess its severity and, most important, what can be done for its control or prevention.
3.3 Soil conservation requirements for sloping land

Handbooks such as the FAO Soils Bulletin 52, ‘Guidelines: Land Evaluation for Rainfed Agriculture’, give some guidance to planners on how to assess the potential degree of soil erosion for an area, but give little indication on how this information can be used, what supporting conservation measures may be available, or what are the limitations of these measures.

For example, the FAO Soils Bulletin No. 52, goes to some length to describe how the erosion hazard may be assessed and suggests the use of various modelling techniques such as the Universal Soil Loss Equation, SLEMSA and others. But, little instruction is given on how the information is to be used once it has been worked out, other than how to calculate necessary ‘rest periods’ for some lands to overcome problems of degradation.

If land-use planners are to produce plans which will lead to the safe and productive use of sloping land, without incurring soil erosion, it is important not only to assess the risk of erosion, but also to have a sound understanding of the causes of the erosion and the possibilities available for its control.

As land slope is not normally an important consideration for wind erosion, the following discussion will be concentrated on aspects of water erosion.

3.3.1 Soil erosion on sloping land

A considerable amount of research and study has been undertaken on the mechanics of water erosion; this subject is now fairly well understood and documented. Similarly, a great amount of work has been devoted to developing different soil conservation practices and techniques.

Unfortunately, the principles behind these subjects are not as widely known as they should be. The result of this is that we see many large and expensive schemes aimed at controlling erosion on sloping land which are only partly effective, or in some cases a complete failure. Sometimes, large sums of money have been needlessly wasted.

There are various reasons for the failure of soil conservation schemes, but one of the most important reasons is the lack of understanding by the planners of the basic processes of soil erosion and the principles of its control and prevention.

These are as follows:

Raindrops falling on a bare soil break down the structure of the surface soil and detach particles. If the land is sloping and the water cannot be immediately absorbed by the soil, or detained by the micro topography, the water moves off down the slope in the form of run-off, carrying dislodged particles with it.

The basic factors affecting water erosion are the erodibility of the soil, the erosivity of the rainfall, the slope of the land and the type of land use.

Diagrammatically, this can be illustrated in a simplified form as follows:

Slope is therefore one of the very important factors in water erosion because of its effect on both the volume and velocity of any water which runs off.

The angle, or degree of slope, is an important factor, but there are four other factors, the importance of which are often overlooked or underestimated; these are length of slope, shape, roughness and aspect.
3.3.2 Gradient or angle of slope

The gradient or angle of slope is obviously of prime importance, as the steeper the slope, the faster water tends to run off. If the water runs off quickly, it has little chance of being absorbed by the soil and, as its velocity increases, so does its ability to dislodge and carry away soil. On flat or gently sloping land, a film of water forms on the surface during intense storms. This helps to dissipate raindrop energy. On steep slopes, the water moves away too quickly and this protective film cannot form.

3.3.3 Length of slope

The length of slope is also important, mainly because the longer the slope, the greater the volume of water which accumulates on it and which will increase in velocity as it runs off, again increasing its potential to dislodge and transport soil particles.

3.3.4 Shape of slope

Slopes are usually either concave or convex in shape. Concave slopes tend to erode on their upper, steeper sections where run-off moves quickly. As the run-off reaches the lower slopes, it tends to slow down and deposit some or all of its sediment load. The problem is dealing with concave slopes then is often one of erosion on the upper sections and deposition on the lower.

Convex slopes, on the other hand, tend to erode less on their upper sections, but to erode rapidly on their lower sections, frequently depositing large quantities of sediment on lower, flat lands or direct into streams.
Because of these differences, the mere shape of a slope can have a big effect on how a particular piece of land should be treated to control erosion.

3.3.5 Roughness of slope

Water tends to run off quickly from smooth, regular slopes. However, if a slope is irregular, rough, and with changes in its micro topography, the movement of water is impeded. Some of it is temporarily detained, the infiltration rate increases and run-off is slowed down.

3.3.6 Aspect of slope

The aspect of a slope can affect its susceptibility to erosion directly and indirectly. The angle at which wind and raindrops strike the surface has a direct effect, while the effects of sunshine and shade, rates of plant growth and preference of animal grazing, have indirect effects.

3.3.7 Soil conservation on sloping land

A great variety of soil conservation practices and techniques have been developed for preventing and controlling erosion on sloping land. These range from simple practices such as contour cultivation, which can be laid out and managed with little training, to complicated, sophisticated soil management and engineering works which require specialized skills for their design, implementation and maintenance. Space does not permit even a brief description of them all here.

Fundamentally, however, what soil conservationists try to do is to introduce and promote stable systems of land use and management which control and prevent erosion in three different but related ways; firstly, by protecting the surface of the soil, as far as possible, from the effects of raindrops directly striking the soil surface; secondly, by trying to ensure that the maximum amount of water reaching the soil surface is absorbed by the soil; thirdly, by attempting to make any water which cannot be absorbed drain off at velocities which are low enough to be non-erosive.

On flat, or gently sloping land, soil conservationists have at their disposal a large array of techniques to accomplish these three aims and the techniques can be used in various combinations to allow for the requirements of different land uses. Thus, if it is necessary to leave the land exposed to the direct action of raindrops for a period so that an annual crop can be grown, compensating techniques can be used which will help infiltration and slow down the speed of run-off.

As slope increases, the soil conservationists' task becomes more difficult. The main problem comes with the increased difficulty in detaining or slowing down run-off to non-erosive rates as slopes increase. But, at the same time, another factor frequently comes into play. Usually, as slopes increase, the soils become shallower and their capacity to hold water decreases.

This, in turn, makes the task more difficult and restricts the options of the planner
to concentrating on practices which aim to ‘roughen the surface’ and protect it from the direct impact of raindrops.

3.3.8 Basic soil conservation practices

Soil conservation measures are normally described under the two convenient headings of biological measures and physical or mechanical measures.

In practice, there is an overlap between the two and soil conservation plans for any area normally consist of both types of measures.

The underlying principle of biological measures is that vegetation is used, either alive or dead, in sufficient quantities to shield the soil surface from the direct impact of raindrops and to create a rough surface which will physically impede run-off and slow it down to non-erosive velocities.

Mechanical conservation works on the other hand do little, if anything, to prevent the effect of raindrop impact, but are designed to slow down, partially or entirely, the movement of run-off water so that the infiltration rate is increased and the velocity of run-off is reduced.

Physical conservation works are normally designed to achieve this in one of two ways: either by reducing the length or changing the degree of slope. For example, contour banks or bunds are used to reduce the length of slope. A well-designed system of contour banks will be spaced close enough together to intercept run-off before the flows become too large or before the flows start to concentrate in channels and to form rills.

On the other hand, bench terraces are constructed to actually change the slope. While the overall slope remains the same, sections of flat, or nearly flat land, are created which allow forms of land use which cannot be practised on steep slopes without causing erosion.

These, then, are the basic principles which guide soil conservationists when they attempt to plan and implement soil conservation measures on sloping land. Although a wide variety of practices and techniques are now known and are available for use, they all have their limitations and these limitations increase with the slope.

3.4 The future for sloping land

As already discussed in Section 1, present indications are that large areas of new land will have to be brought into production over the next fifty to one hundred years. But, because most of the best land is already in use, considerable areas will be sloping and have erosion problems. It can be expected that land-use planners will be called upon to help decide how best to use this sloping land. In preparing plans for these sloping lands, increasing attention will need to be given to preventing and controlling erosion. A closer relationship will need to be developed between land-use planners and soil conservationists and at the same time land-use planners will need to have a better understanding of the process of erosion and methods for its control than has been necessary in the past.

Included in this understanding must be appreciation of the fact that in many coun-
tries, particularly in parts of Asia and Africa, population densities are high and many sloping areas are already densely settled and cultivated.

These areas are already degrading. Not only are farmers’ yields declining, but erosion from the sloping areas is causing serious problems downstream, including the silting up of streams and dams, damage to hydro-electric and irrigation schemes, restrictions to navigation in rivers and harbours and an increased frequency and severity of flooding. The causes of these problems are now becoming widely understood by politicians, administrators and, to some extent, the public in general.

The result is that technical agencies are now being increasingly asked to assist. More and more demands are coming to the agencies to produce and implement sound land use and soil conservation plans, which will prevent the downstream problems and at the same time improve the lot of the land users on the slopes.

The technical agencies and their staff always seem ready to tackle these problems, but once work starts they are usually faced with a dilemma.

Accepted principles of land use – the very basis for sound-land use planning and soil conservation – teach us that each unit of land has its own particular characteristics, its own capabilities and its own limitations. We therefore plan our systems of land use to fall within the capabilities of the particular unit of land being studied. If this is done properly, we produce plans which can lead to optimum, sustainable production.

We know from long experience that particular soils, on particular slopes, in certain environments, can only be safely farmed in certain ways. Once we try to use these units of land in a way which exceeds their capabilities, we inevitably enter into a cycle of loss in productivity and degradation. For example, in many of the tropical areas of Africa and Asia, farmers were able to successfully grow food crops on steep erosion-prone slopes for many hundreds of years by following systems of shifting cultivation in which the land was cropped for short periods and left for long periods to recuperate under a ‘bush fallow’. Population numbers and a shortage of land has made this system impossible now in most areas and, with the reduction or even complete abolition of the fallow periods, soils are degrading and yields are declining.

The result is that we are now being asked, in many countries, to produce plans for sloping land which is already densely settled and under forms of land use which are leading to land degradation.

To introduce correct land use would usually require that some of these people be moved from the steep slopes and that the types of land use be changed to systems which are less intensive or at least which are compatible with the capabilities of the land.

Here we encounter the problems. The realities of the position are that for political, social and economic reasons, it may not be possible to move the people. Other, more suitable land may not be available. But, even if it is, people are generally reluctant to move from their established homes, families and communities. At the same time, governments are generally reluctant to intervene with resettlement schemes as they are administratively difficult, often highly unpopular with the people, usually costly and frequently fail.

On the other hand, efforts to change the land-use pattern without moving people, e.g. changing from one form of arable farming to another or changing from arable farming to, say, livestock production, is normally a slow and difficult process.
There may be a number of reasons why changes in land use are difficult to bring about, but where commercial agriculture is being practised, farmers are growing certain crops because of the pricing structure and are unlikely to change unless it can be clearly demonstrated that the growing of other crops can be at least as financially attractive.

Where subsistence farming is practised, as in the case of most sloping land in the densely populated developing countries, the need to grow annual food crops to meet the immediate needs of the family is the farmer's primary concern.

Until the subsistence farmer is assured of his immediate food needs, he will show very little interest in changing his form of land use.

Under these conditions, should the planner produce plans which are technically sound, which if applied will lead to sustainable, productive agriculture, knowing that such a plan has little, if any, chance of being implemented with the present population pressures and political, economic and social conditions?

Or, should he take the existing conditions into consideration and produce some form of compromise plan which will not be fully effective, but which could be implemented and at least slow down or prevent some of the land degradation which is presently occurring and at the same time improve the lot of the farmers to some extent?

Perhaps the only way to look at these problems is within the overall national context. If the sloping lands are only suitable for producing commodities for 'off the farm sale', i.e. timber, fuel and cash crops, must there not be a guaranteed system of providing staple food to these areas from the flatter land if stable forms of production are to be brought about? Can we produce acceptable plans which will provide for the supply of staple foods from other areas or must we wait in the hope that political, social and economic conditions will change to the extent that we are able to implement orthodox plans?

This paper does not present solutions, but it is hoped that it will stimulate discussion of the problem.

In many cases, we cannot simply evaluate sloping land and say – not suitable'. In many cases, the people are there, these lands are being farmed, yields are declining. How do we evaluate and plan?

References

Discussion

Beek: Sequential analysis, i.e. short and longer term planning is needed; therefore the choice of the LUT is important; we may become more involved in decision making and thereby shorten the lines of communication between the land evaluator and the user.

van Mourik: To which extent can the gap be closed between the planner, administrator and the farmer in fact the farmer does everything (planning, budgeting and execution); are there studies to indicate how the distance between farmer and planner may be shortened?

Sanders: If plans are to be meaningful then the farmer must be more involved; the planner must go out and talk to the farmer and get involved to understand what the problem of erosion means to the farmer; the farmer is firstly concerned to produce enough food for his family, then comes the rest.

Fernandez: How to evaluate land use in densely populated areas? A method is to look at the traditional technology of the best farmer and address this to the other farmers; an example can be given from central Mexico where top-down and bottom-down planning are realized through this method.

Bennema: I support the comment made by Fernandez and would like to point out an often overlooked important soil property: in low input agriculture the influence of the meso fauna in the development of bio-pores is important; for example in the Kisii area (South West Kenya) no erosion occurs on intensive cultivated slopes of 15% on soils that contain up to 80% clay, because of the many termites, which cause the formation of many pores, thereby increasing the permeability of the soil.

Eppink: How can the experience of farmers who cultivate slopes be put to the people that have never cultivated sloping land.

Fernandez: This is possible on local level when the farmers are introduced to the new methodology and techniques by their farming colleagues.

Luning: What is the experience of the FAO with the ‘food for work’ programme?

Sanders: FAO has much experience in this matter and food for conservation works is still being undertaken; however, the real problem of erosion may be locally checked.

Millington: The approach undertaken in central Mexico is very interesting, but how to feed back this information by means of the extension mechanism; the traditional conservation techniques are easily accepted at the local cultural, economic and social level; the technical constraints to measure the solutions are not very good but acceptable; in Sierra Leone a method was developed to feed back the results of successful field trials into the extension mechanism.

Stocking: What are the implications? Are we looking at the problem from the wrong end? What is best – that the land evaluation techniques are brought to the farmer or that land evaluation must meet farmers’ needs and to see how the land conservation fits into these needs?

Sanders: Yes, that is the way it should be done.
Mitchell: How can we get the farmer to accept or to adapt the conservation systems under the present land tenure system; many conservation plans cannot be carried out because the farmer has only a say over the land when he is cropping it; thereafter other users occupy the land; thus the matter of land legislation is important.

Dudal: The responsibility rests also with the government; they are often prepared to put up an army and huge sums of money to defend one inch of their boundaries, but are reluctant to allocate money to combat the loss of several inches of soil from the surface; they (these countries) lose their independence because of food inputs.