Land evaluation for land- use planning and conservation in sloping areas

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Foreword

The International Workshop on Land Evaluation for Land-Use Planning and Conservation in Sloping Areas was held at the International Institute for Aerospace Survey and Earth Sciences (ITC) in Enschede, The Netherlands, from 17-20 December 1984. It was organized jointly by the International Society of Soil Science (ISSS), in particular the ISSS Working Group on Land Evaluation (Committee VI: Soil Technology), the Food and Agriculture Organization of the United Nations (FAO), in particular FAO's Land and Water Development Division, and ITC's Department of Land Evaluation, Resource Surveys, and Rural Development.

The Workshop was one of a series of Workshops elaborating on the FAO Framework for Land Evaluation. This Workshop differed from the previous ones because, whereas they dealt with a major kind of land use (Rain-Fed Agriculture, Irrigated Agriculture, Forestry, and Extensive Grazing), this one dealt with one particular problem area: that of Sloping Land.

The Workshop was attended by 56 participants from 18 countries. It generated a total of 20 papers on the Workshop themes:

A. The application of the FAO Framework for Land Evaluation in land-use planning and conservation in sloping areas: potentials and constraints.
B. Erosion hazard and conservation needs as a function of land characteristics and land qualities.
C. Land evaluation for conservation to support decisions in land-use planning.

As ILRI has had a long involvement with publications on land evaluation, it was with pleasure that we could respond to the request of ITC to publish the Proceedings of the Workshop. They contain a list of recommendations compiled by the participants, the opening addresses by Prof. Dr Ir K.J. Beek, Rector of the ITC, and Dr Ir W.G. Sombroek, Secretary General of the ISSS, all 20 papers, and summaries of the working group sessions. The Proceedings of the Workshop were edited by Dr W. Siderius of ITC.

Dr Ir J.A.H. Hendriks
Director, ILRI

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Recommendations

The workshop delegates recommend:

1. that an inventory of the present status of soil erosion be established with particular reference to critical areas (erosion 'black spots') by means of static and dynamic maps of erosion hazard; such maps can be used to assess the efficiency of conservation policy and to indicate areas where different land-use alternatives should be considered,
2. that land information systems be developed for land evaluation; as a contribution to such development a joint workshop on soil conservation, land evaluation and soil information systems should be held in 1986,
3. that further work on methods of land evaluation concentrate on improving the existing sets of guidelines for major kinds of land use, rather than preparing new guidelines for problem situations; in doing so, the role of the farmer should be emphasized,
4. that study be conducted on the effects of erosion and the benefits of conservation on levels of production, viewed both economically and from the point of view of the farmer; that planning of conservation measures take into account sustained yield on a socially equitable basis,
5. that methodological work on proces-orientated models be promoted; such models help to identify critical gaps in knowledge and promote understanding of the structure and dynamics of the processes which determine the permanent productive capacity of land,
6. that a central agency for the coordination of data acquisition and data quality control be set up (ISRIC would qualify if adequately funded),
7. that the land evaluator follow up his work into the stages of planning and implementation in association with land-use planners and decision-makers, emphasizing a multi-disciplinary approach,
8. that local staff be involved in all stages of the land evaluation process in order to secure continuity in the application of the results of the evaluation to land-use planning,
9. that the need for a national policy and strategy on soil conservation be recognized in all countries; in support of this, there should be a national body responsible for conservation, including both planning and training,
10. that the integration between conservation and more broadly based development programmes be promoted, including the integration of conservation and extension services,
11. that the farmer be involved in conservation planning; this should include studying his knowledge of farming and conservation practices,
12. that the views of the land managers (e.g. farmers) be compared and reconciled with those of the technical experts; taking into account individual and the community needs as well as physical resources in order to arrive at land-use changes will be acceptable to all parties.

Opening addresses

K.J. Beek,

Rector ITC

Ladies and Gentlemen,
On behalf of the ITC I have the pleasure of welcoming you at the beginning of the International Workshop on land evaluation for land-use planning and conservation in sloping areas.

I welcome especially Dr. W.G. Sombroek, Secretary General of the ISSS, co-sponsor of this Workshop, and who will perform the official opening this morning.

Furthermore I acknowledge the cooperation of FAO and UNEP. A special welcome to Mr. Maurice Purnell, who at the FAO Headquarters engineers most activities and publications that are concerned with land evaluation.

It is a great pleasure for the ITC to contribute with the mentioned organizations in promoting the formulation of procedures and guidelines in land evaluation, which should eventually lead to better land use. As you may know, ITC is most concerned with surveying and mapping in the developing countries.

It is especially in these countries that we notice a rapid degradation of the land and vegetation in sloping areas. Population densities are high, often attracted by a relative high natural fertility of the soil and the healthier climate of the higher altitudes. Furthermore, population in these countries tend to duplicate almost every twenty years.

There is a saying: make the maps you need in time, so you have them in time of need. Unfortunately the needs are very pressing, maps may not be available and represent only one aspect of many inputs that are needed for a more harmonious development.
The question then is: what maps and information are most needed, and how can this be best achieved?

In a way, this meeting is exceptional in the sequence of international land evaluation workshops, because it deals with a problemarea: sloping land. Soil erosion and soil conservation have a central position. Indeed previous meetings have concentrated in the first place on major kind of land use. Land evaluation manuals could thus be prepared for rainfed agriculture, irrigated agriculture and forestry. For this purpose similar workshops have been held in Rome and in Wageningen.

The most recent workshop of this kind, also with co-sponsoring of ISSS, FAO and ITC was held last year at ILCA, Addis Ababa, concerning extensive grazing.
Professor Vink, who recently retired from the Amsterdam University, and who is one of the nestors of land evaluation considered the meeting of 1972 in Wageningen one of the three highlights in his career. It was the start of the FAO Framework for Land Evaluation. I share this view, in that the framework has created a new possibility for different disciplines to cooperate in a well structured manner.
Indeed, the previous workshops in this respect have been very fruitful. Most important was that the participating disciplines have accepted the Framework concept and procedures in their discussion. I hope that this will also be the case in our discussions this week. I expect that most of you here received the FAO Guidelines for Land Evaluation for Rainfed Agriculture.

Those who have not, will have some homework to do in the evenings, to be able to participate in the working group sessions.

As I said, this workshop is different because it deals with a land problem: sloping areas, rather than with a major kind of land use. On the other hand, in land evaluation for irrigated agriculture we have also dealt with rather specific physiographic conditions.

Most important for this meeting will be to find out if the soil conservation specialists see a future for the application of the FAO Framework in sloping areas.

Soil conservationists, and especially the geomorphologists and hydrologists amongst them have a longer-standing tradition than soil surveyors and land evaluators in the use of quantitative methods of analysis and of simulation models. It is of great importance that our effort towards more quantitative approaches in land-use planning will run parallel. The invited paper of Dr.Driessen wants to provoke a discussion in that direction!

Before you ask me, I'd better raise the question myself, why are we organizing a workshop on sloping areas in probably the flattest country of the world?

a. If we tell you first that today is the 33rd anniversary of the ITC. Professor Hallsworth will present the honorary lecture on the subject: Resources for the Future, measuring and managing the ultimate limits to growth. I expect that sloping areas will be an integral part of his presentation.
b. The ITC, being concerned with the application of aerial photography and satellite remote sensing, is of course very specialized in extrapolating information related with slopes, because of the stereoscopic vision available.
c. Nowadays, ITC is becoming more and more involved in the research and education concerned with land information systems. We hope to receive some guidance from you, as regards the future of land information systems, as a tool for land-use planning of different levels of detail. The system approach of the land evaluation methodology if linked with the hydrological models and methods and in soil conservation could be important means for setting up land information systems in support of watershed management.

ITC encompasses most disciplines required for setting up such systems, and is very much in need of input.

Therefore I may confess that the efforts of ITC in organizing this workshop here this week, reflect a certain degree of self-interest. In return, we shall do our best, during the excursions, to give you a good introduction to the possibilities of our data-processing laboratories.

Furthermore, you may be assured that your knowledge and experience will be immediately put to use in the course programme for our students from the developing countries.

I should like to use the occasion to raise a few questions, which I hope can be given attention during the various discussions. In this respect my curiosity may be partly traced to my interest in the mapping of land evaluation as such.

a. Will it be useful, for enhancing multi-disciplinary cooperation, to prepare guidelines for land evaluation, not only in connection with major kinds of land use, but also in connection with specific problem-land situations, such as the sloping land areas.
b. How can land evaluation include the interaction between different land use systems,

linked within one sloping landscape by the same hydrological cycle?

c. How can land evaluation make explicit recommendations separately for the short term and for the long terms?
   Here experiences from developed countries, where long-term policy in the conservation of natural resources is under high pressure of short-term vision, will be relevant.
d. If there is a future for computerized land-information systems in sloping areas, what effect will this have on data collection, updating of information and monitoring?
   Should these systems be site-specific?
e. Since the framework for land evaluation distinguishes between land and use, how can the functioning of the integral eco-system be evaluated without a too arbitrary sub-division in sub-systems? This question is of particular importance when long vegetational cycles are concerned such as protective forest.
f. Especially for the purpose of nature conservation, how can the immaterial functions of natural reserves be included in the land evaluation procedure?
   This may be of great importance for the conservation and use of for instance tropical rainforests.
g. How do the different mapping scales affect the purpose and procedures in land evaluation?
   Adherence to specific mapping scales may avoid some confusion during the discussions.
h. I should appreciate suggestions for future activities of the ISSS-Working Group on Land Evaluation. Personally I should like to organize a joint workshop with the Working Group on Soil Information Systems on 'Land Evaluation and Land Information Systems'.

Now I should like to say a few words about this week's programme. Our students know, that whoever comes to the ITC, has to work very hard. The idea is indeed that we work together, in a rather informal manner. This morning three presentations by Purnell, Driessen and Sanders are the principal background for further discussion. This afternoon will be dedicated to the ITC anniversary ceremony with the lecture of Professor Hallsworth followed by a reception. The next four days will include a morning programme of lectures in this auditorium, where, apart from the workshop participants, observers will be welcome.

During the afternoon we shall split up in working groups, to discuss and make recommendations on the seven themes we have distinguished for this purpose. These discussions are open only to workshop participants.

There will be two excursions, one to the ITC laboratories as I mentioned, and one, on Thursday afternoon to the Twickel Estate. This Estate is an interesting example of conservation of monuments. It is a sort of castle which has been permanently lived in since the thirteenth century. It represents the largest private estate in The Netherlands. Our visit is rather unique since very few people are admitted into the house to see the beautiful collection of fine arts, including antique maps, which will be shown to you. The ITC contributes to the conservation of this estate through the monitoring of changes in the forest vegetation from the air.

I am very grateful that Professor Anthony Young is with us this week. I have asked him to coordinate the presentation of results from the working group sessions on Friday morning.

Professor Young has been closely connected with the preparation of FAO quidelines for land evaluation and has a wide experience. He is now employed with the ICRAF, the International Centre for Research on Aero-Forestry in Nairobi.

Finally, I should like to thank you all for honouring us with your attendance. We have an excellent group bringing in experience from North and South America, Africa, Asia, Australia and Europe. Our land evaluation methods are raising expectations all over the world, especially in the developing countries. I wish you all very much pleasure and success in this week's deliberations. I am convinced that the result will be significant.

Thank you for your attention.

W.G. Sombroek,

Secretary General of the ISSS.

Prof.Dr. K.J. Beek, as Rector of ITC and Chairman of the ISSS Working Group on Land Evaluation, Mr. M. Purnell as representative of FAO, Ladies and Gentlemen, Colleagues,

It is very much a pleasure to open this meeting on behalf of ISSS, and to bring you the greetings of our President, Prof.Dr. K.H. Hartge, and the whole Executive Committee of our Society. I happen to know the host institute of our meeting quite well, not only because I studied at ITC way back in 1959, but also because the Centre which I have the pleasure to direct, ISRIC in Wageningen, has very close ties with ITC. I therefore am well aware that ITC is in a well-placed position to promote the idea of multipurpose land evaluation. The interdisciplinary character of the subjects taught there at your various courses for so many students from all over the world, and the developing countries in particular, is a natural breeding ground for the further development and propagation of the land evaluation methodology.

The 'land evaluation' approach to the interpretation of soils and land characteristics for a variety of use was initiated already well before the Working Group of ISSS on the subject came formally into being, at the 12th Congress of Soil Science in New Delhi.

A combined effort of a Wageningen group and a FAO group of scientists resulted in a coherent approach in the early seventies with your, Prof. Bennema's and Dr. Ph. Mahler's ideas as useful starting points. The resulting 'Framework for Land Evaluation', published by both ILRI in Wageningen and FAO in Rome, has gained a large degree of adherence in the years since. FAO elaborated guidelines on Land Evaluation for Rainfed Agriculture (1983) and for Irrigation, the latter as yet available in draft only. Jointly with IUFRO (the International Union of Forest Research Organizations) and FAO, guidelines were developed on Land Evaluation for Forestry, at a Wageningen Symposium of the ISSS Working group in 1980, published by the FAO Forestry Department in 1984. Jointly with ILCA (International Livestock Centre for Africa) and FAO, guidelines on Land Evaluation for Extensive Grazing were developed at a symposium of the Working Group in Addis Ababa, and its Proceedings have just been published by ILRI. Now, jointly with FAO and UNEP, you intend to establish guidelines on land evaluation for land-use planning and conservation in sloping areas, in short Soil Conservation.

I foresee a need for similar guidelines on land evalation for wind-erosion prone areas, and also for tropical forest areas, with particular attention to nature and gene plasm conservation (in short: Fragile Ecosystems). Your Group may seek the active support of UNESCO and IUCN in such an effort.

The topic of the present workshop – and very much the topic-of-the-day! – concerns soil erosion and soil conservation. Soil erosion, its control and prevention, has for several decades been underrated in research and development programmes. It has been given scant consideration, ever since the overwhelming attention to the subject in the USA before the second World War. Recently however, things have changed, and now everywhere scientists, government officials, politicians and the public-at-large have become aware of the rapid deterioration of the soil resources of the world. It is most spectacular in the tropics and subtropics, but becoming apparent also elsewhere as a result of over-mechanization and too heavy emphasis on chemical fertilizers. Some examples of this awareness are:

- FAO devised its World Soil Charter
- UNEP developed a World Soils Policy, and an Action Plan to combat desertification
- Several major international congresses have been held on Soil Conservation (Gent in 1978, Silsoe – UK 1980, Hawaii in 1983, Maracai – Venezuela planned for late 1985)
- The ICSU-SCOPE Committee (Scientific Committee on Problems of the Environment) devised a Land Transformation research project
- IFIAS (the International Federation of Institutes for Advanced Studies) started a 'Save our Soils' project, and its project director Prof. Gordon Hallsworth is our main speaker today.

ISSS itself created a special standing Subcommission on Soil Conservation and Environment at its 1984 New Delhi Congress, and its Chairman Dr. Klaus Flach is among us. I trust that there will in fact be a close cooperation between that Subcommittee and your Working Group on the elaboration of land evaluation guidelines for soil conservation and putting them in practice.

There is no doubt, therefore, that the subject of this workshop is very timely: to develop guidelines/tools for land-use planning in water-erosion prone areas the world over. I do hope however that it will be followed by a vigorous effort by your Group, by FAO, UNEP and especially national and local institutions in the countries concerned to put this into practice at watershed and farmers' level, before the situation has deteriorated beyond the point of no return. The situation is already quite dramatic in many areas! Fortunately the public awareness is growing rapidly. I recall a huge billboard near Caracas airport saying (freely translated): 'Your land; don't squander it, but cultivate it; then I shall be a great land for you and your children'.

In concluding, I wish you, Mr. Chairman, and all participants much success with this workshop, and even more with the follow-up, literally at grass- roots level.

With these words I declare this ISSS Workshop on Land Evaluation for Land Use Planning and Conservation in Sloping Areas officially opened.

1 Application of the FAO framework for land evaluation for conservation and land-use planning in sloping areas; potentials and constraints

M.F. Purnell

Land and Water Development Division FAO, Rome

Abstract

An outline is given of the methods proposed by the FAO Framework for Land Evaluation and the Guidelines for land evaluation for rainfed agriculture and for forestry, with particular reference to those applicable for conservation and summarily for land-use planning. The advantages and limitations are briefly discussed.

1.1 Introduction

Traditional economic textbooks used to state that there are four factors of production: land, labour, capital and management, and that land is given and fixed. The idea that land is fixed is true only in the most simplistic way – that the total area does not vary much. The amount of land for any specific purpose can vary enormously in response to demand and supply and to the inputs which are made. This is particularly true of the marginal lands on the fringes of the sown area, such as in semi-arid climates or in hilly topography. Development of such areas may be expensive and physically difficult, and may be hazardous with regard to economic success and damage to a fragile environment.

The FAO Framework for Land Evaluation (FAO, 1976) was developed in response to this situation in order to provide a systematic way of looking at various options and predicting the results of alternative courses of action. Such land evaluation is an essential prerequisite for rational land- use planning, which must be based on a knowledge of what land resources are available and what they are suitable for. This paper considers its application for a special case: the sloping lands of the world and with particular reference to the use of land evaluation for planning conservation measures.

A brief account will be given of the methods outlined in the framework and elaborated in the Guidelines for Land Evaluation for Rainfed Agriculture and for Forestry (FAO, 1984 a and b). The paper will go into more detail on the methods for evaluation of sloping lands and for conservation measures, and its application in various situations.

1.2 Sloping lands and conservation

Since we are dealing with conservation on sloping areas it may be as well to consider the world's sloping lands. Erosion is not confined to sloping land – the Argentine pampa is very flat but nevertheless has severe gully erosion. On the other hand not all sloping lands are very erodible; some of the porous tropical volcanic soils are rather resistant. However water erosion does normally increase with slope though the amount varies with different soils and rainfall conditions.

Some figures for the areas of sloping lands derived from the Soil Map of the World are shown in Figure 1.1. About one third of the land area has dominant slopes of 8-30%. Land with slopes over 30% is about one sixth ranging up to more than a quarter in Southeast Asia whereas Africa is notably flat. Of course within the continents there are marked differences between countries, as for example between Sudan and Ethiopia.

To take another angle the results from the potential population supporting capacity studies carried out by FAO recently (FAO 1982, 1984c) indicate the countries which are likely to have critical conditions for self-sufficiency in food. Many of these countries are in the semi-arid zones but the other main critical regions are the hill and mountain regions of the Andes in S. America and the mountain belt stretching from Turkey through the Himalayas. Pressure on the land in these mountainous areas is therefore an important and increasing problem.

Figure 1.1 Percentage Areas of Sloping Lands. (derived from Soil Map of the World).

a. Developing Countries:

Slope	Africa	S.W. Asia	South America	Central America	Southeast Asia	Total Area 10^6	%
0– 8%	58	45	52	35	40	3340	51
8–30%	34	31	30	40	31	2107	33
>30%	8	24	18	25	29	1048	16

b. Some Developed Countries.

Slope	N.America	Europe/N.Asia
0– 8%	36	43
8–30%	50	38
>30%	14	19

c. Country Comparisons.

Slope	Sudan		Ethiopia	
	hax10^6	%	hax10^6	%
0– 8%	184	74	57	46
8–10	49	20	30	25
>30%	17	6	35	29

1.3 The framework for land evaluation

Presumably people are already familiar with the Framework for Land Evaluation (FAO, 197) so this section will concentrate on some features of the Guidelines for Rainfed Agriculture and for Forestry (FAO, 1984 a and b). These volumes are to be supplemented by similar Guidelines for Irrigated Agriculture in early 1985 and for Extensive Grazing in 1986.

The diagram representing the procedural sequence for land evaluation is the same as in the Framework and the results which it is expected to produce are the same:

1. Data from basic surveys;
2. Descriptions of land utilization types;
3. Land Suitability classification;
4. Management specifications for land utilization types on land units.

However the guidelines go into much greater detail about the actual procedures which can be used to describe land utilization types, land-use requirements and limitations, to rate land qualities and to match the land- use requirements with the land qualities and arrive at an overall assessment of the land suitability. These are guidelines rather than manuals because they indicate alternative ways of proceeding and it is intended that users should be selective in taking those elements which fit their requirements.

The suggestions for description of land utilization types (LUTs) closely follows the Framework with rather more emphasis on the levels of input. The Forestry Guidelines is a good deal more specific in indicating the kinds of forest land utilization type.

The methods for determining the land-use requirements and limitations for the LUTs are given in detail. The publication does not, however, attempt to give critical limits for the requirements (except as examples) because it is believed that this is not possible on a global scale and could almost certainly lead to misunderstanding and misuse.

The requirements are divided according to whether they mainly affect the crop or the management or the environment, as shown in Figure 1.2. It is possible in some circumstances to add requirements, which mainly affect development (such as clearing of farmers attitudes).

Not by accident, the land-use requirements are exactly paralleled by the land qualities. Clearly this facilitates both understanding and the matching of the land-use requirements with the land qualities. Much of the publication is taken up with means of characterizing and rating the land qualities.

One difference from the Framework is that 'crop yield' is no longer treated as a land quality but rather as a different kind of information. Obviously if one knows the yield there is no point in making an elaborate evaluation in order to predict the yield. This is particularly important for production forestry where the yield can be measured without harvesting the crop, and various kinds of site index provide fairly reliable estimates of yields in temperate forests. For tropical plantations data is often lacking and the method may be inapplicable for mixed tropical forests. Any existing crop yield data can be applied to improving the reliability of prediction from land quality assessment by means of regression analyses, paying particular attention to differences in management such as fertilizer applications.

Formats are given for rating the land-use requirements and land qualities individually. This helps to emphasize the need to give not only the optimum conditions but

Figure 1.2 Requirements of land utilization types for rainfed crop production.

A. Crop Requirements		
Energy	- Radiation	
	- Photoperiodocity	
Temperature	- Total requirements	Growth
Moisture	- Critical periods	cycle
Oxygen (soil drainage)	- Nutrient availability	
Nutrient availability	- Nutrient retention	
Rooting conditions		
Conditions affecting germination or establishment		
Air humidity as affecting growth		
Conditions for ripening		
Flood hazard		
Climatic hazards	- Frost	
	- Storm	
Excess of salts	- Salinity	
	- Sodicity	
Soil toxicities		
Pests and diseases		
B. Management Requirements.		
Soil workability		
Potential for mechanization		
Conditions for land preparation and clearance		
Conditions affecting storage and processing		
Conditions affecting timing of production		
Access within the production unit		
Size of potential management units		
Location	- Existing accessibility	
	- Potential accessibility	
C. Conservation Requirements.		
Erosion hazard		
Soil degradation hazard		

also the response to less than optimum conditions, as well as the cut-off points beyond which the land is not suitable for the specified land use. Trying to fill in such forms commonly emphasizes the lack of reliable data and suggests research priorities.

The process of matching is also described in some detail since it has aroused many questions about how to do it in practice. The procedure proposed is to rate either crops or cropping systems for each land quality individually and combine them to make suitability assessments for crop growth, for management and for conservation, which are then combined into overall suitability classes.

In the case of land qualities related to conservation requirements the matching procedure is in principle to determine the estimated soil loss of each LUT (crop and management) on each land unit. If the tolerable soil loss is exceeded the land is unsuitable for that use. To reduce calculations (when made by hand rather than computer) LUTs may be grouped and matched with classes of erosion hazard. Less than optimum conditions are usually represented by land on which increasingly onerous conservation measures must be used to keep the soil loss at an acceptable level. An iterative process is suggested for bringing the land limitations and land improvements to the optimum combination.

The land suitability classes thus determined may be adequate for qualitative evaluations. For quantitative economic evaluation, systematic financial and economic analysis is applied to the land-use systems and the provisional land suitability classes may be altered as a result. Such economic analyses are particularly problematic for the conservation component of the land evaluation, for the reasons mentioned in section 5.

The land evaluation is not complete without an economic and social study and an environmental impact analysis. The social study is necessary to ensure that any recommendations meet the needs and have the approval of the local community, without which they are doomed to failure. The environmental impact study is partly to ensure that on-site degradation has been thoroughly covered, but more particularly to investigate the off-site or downstream effects. The Guidelines do not go into detail about the methods to be followed. The impact may be favourable as well as unfavourable, particularly when the land use is forestry, and this may provide a strong argument in favour of maintaining forested areas which might yield higher short-term returns under agriculture.

The procedures may appear complex so a step-by-step guide is given as an appendix. In practice once the method is tried there is little difficulty in following it. Where there are a large number of LUTs and many land units in the survey area the process may be tedious. However computerization of the process is quite possible (e.g. the Land Evaluation Computer System described by Wood and Dent, 1983, see Figure 1.3) and will no doubt become increasingly common.

1.4 Application to sloping lands

Some land qualities and land characteristics are of special importance for sloping areas, in particular the erosion hazard, which is dealt with in the next section, and accessibility, size of potential management unit and potential for mechanization.

In addition there is a land characteristic, generally known as 'aspect', which is important for crop growth through its effect on radiation, soil moisture, and winds. A good example is in the hilly loess regions of China where on the steeply eroded gully sites there is a notable preference to grow sorghum and winter wheat on the south slopes which receive more radiation and, on the north slopes, potatoes which respond to the greater soil moisture availability and can produce well with less sunshine. For forestry it is common to select different species for planting on North and South slopes, though this is complicated by soil depths and wind direction and speed which affect losses by windthrow. The guidelines do not rule out using a combination of land qualities and land characteristics and 'aspect' may be a case where a land characteristic can most conveniently be used.

Because of the immense differences in the physical and social conditions on the sloping lands, it may be difficult to make generalizations. Almost any detailed statement about the effect of land qualities on the productivity of sloping lands is likely to be contradicted somewhere.

1.5 Application to conservation

The Framework takes into account the problem of conservation of the environment in two places: in the matching procedure there is provision for conservation requirements, by the land quality 'erosion hazard', corresponding to the land use type requirment or limitation. After the land suitability has been ascertained there is provision for environmental impact analyses.

This corresponds, approximately, with the concept of on-site and off-site effects or upstream and downstream effects. In general it is more straightforward to measure the downstream effects and particularly to put an economic valuation on them. The costs of flooding, silting, dam site sedimentation, etc. can be estimated in monetary terms more readily than the loss of production from eroded fields.

For assessment of the water erosion hazard land quality, the guidelines for land evaluation for rainfed agriculture suggest five methods:

1. The Universal Soil Loss Equation (USLE) suitably modified;
2. The FAO soil degradation assessment methodology (FAO 1979);
3. The Soil Loss Estimator for Southern Africa (SLEMSA);
4. Local methods based mainly on slope;
5. Observed present erosion.

Each of these has some advantages and some disadvantages: number 3 for instance is only suitable for large areas at small scales, for example the rating of the soil units of the Soil Map of the World. This is not the place to go into the details of the methods (see FAO 1979, 1983 b).

The FAO publication Land Evaluation for Forestry (FAO, 1984) draws attention to another issue, that of classifying the suitability of land for 'conservation' forestry. In this case the significance of the land qualities is reversed and it is relative need for land and water conservation rather than suitability for sustained production that is the major determinant. Both data collected and the method of assessment need to be modified to predict changes in catchment erosion in relation to vegetation management and the distinction between land-use requirements and land qualities almost disappears. For reclamation forestry both the degree of degradation and the expected improvement from afforestation determine the relative need. When rare or endangered species are to be preserved specialized studies are needed for their preservation and economic (quantitative) land evaluation ceases to be a determinant.

The results of an erosion are generally expressed in terms of proportion of the surface affected and the soil loss in tons/ha. Satisfactory quantified results can be obtained in these terms, though the investigations are not easy and more research is needed to improve reliability of the results. However for the purpose of justifying soil conservation projects within land-use planning programmes, it is necessary to make an economic analysis in terms of costs and benefits. Difficulty is experienced with valuing goods and services which are not traded and with discounting procedures for very long term effects. The economic analysis depends on changes in productivity with and without the project. It is therefore necessary to convert soil losses into decreases in productivity which can be given a monetary value. This problem has not been satisfactorily resolved as yet.

More data is required relating soil loss to productivity loss. It also has to be recognized that sometimes the losses and gains are mainly downstream and in others mainly upstream. For example the farmers on deep loess in the hilly loess area of China lose little from erosion, but the silting effects downstream in the Lower Yellow River floodplain are very expensive. On the other hand downstream effects do not concern Lesotho but the losses of land by erosion are disastrous for the farm economy.

This account would not be complete without mentioning the Land Evaluation Computer System developed by a FAO project in Indonesia (Wood and Dent 1983), and firmly based on the Framework (see Figure 1.3). The conservation module developed

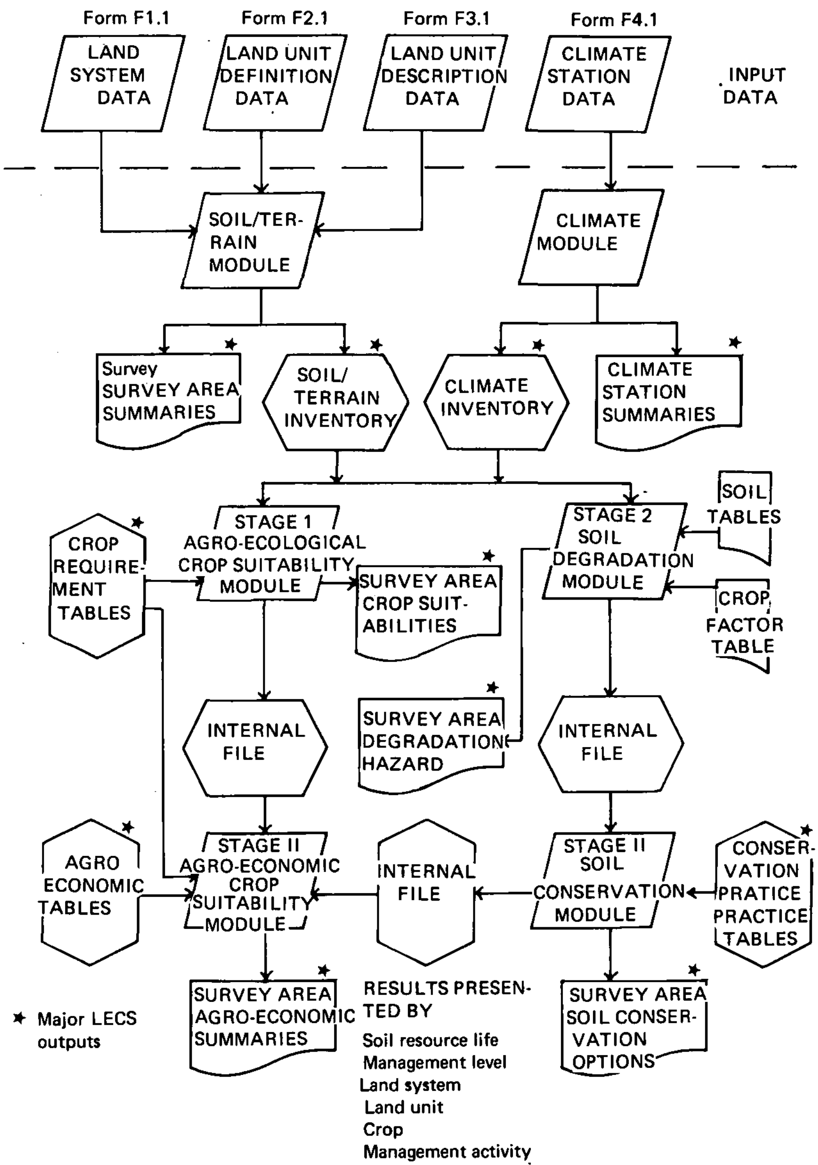


Figure 1.3 Overview of land evaluation computer system organisation.

for the system has two stages. First the calculation, based on a modification of the USLE, of the potential erosion losses for each soil unit and actual soil loss for each cropping system and, after estimating the tolerable soil loss, the calculation of the level of soil conservation required. The second stage is to evaluate soil conservation options relative to stage I results, cost the selected options for use in the Agro-economic crop suitability module and select of optimum use for each scenario. The structure of the modules are shown in Figures 1.4 and 1.5. It may be mentioned that the conservation module is the most complex of the components of the system.

The LECS is a static model, though it contains dynamic sub-models, for example related to crop moisture requirement. In general whereas static models can cope with many parameters dynamic models become unworkable with more than a few. It would be desirable to develop models which can show results of interactions between land resources, erosion, conservation measures, and productivity over future years, because results may not appear quickly or may be different in the first years from what happens later.

It is often stated that such models are only as good as the basic data fed into them. While it is true that uncritical use of results from a model supplied with poor data is dangerous, nevertheless we have to work with the data available to make urgent dicisions now. This is where the iterative process emphasized in FAO can be used. By using models with a range of exogenous data to simulate various options it is possible to get a feel for the probable results of various scenarios. The analysis should be judged not so much on whether the internal results are 'correct' as whether the operator gets the kind of output he needs to make an informed judgement. It has been said that 'art can overcome man's characteristic weakness of learning only from his own experience so that the experience of others is wasted on him. From man to man .... art can convey the whole burden .... of the experiences of other men and enable us to assimilate them as our own' (Solzhenitsyn Nobel lecture). Perhaps the systems analysts and model builders should be judged by their capability to perform the same creative miracle.

1.6 Advantages and constraints

Traditionally land classification for conservation has used the Land Capability Classification developed by the Soil Conservation Service (SCS) of the United States Department of Agriculture, or some local adaptation of it. This provides a simple, eight class system, indicating the kind of use which land can support without degradation, too well known to need description here. As this was developed specifically for conservation it has often served this purpose well, even when taken far out of the context of US agriculture. It has been less successful in classifying land for other purposes, such as land-use planning for integrated rural development. Even the SCS is increasingly using the Land Evaluation Site Analysis approach to complement or replace the land capability classification.

However even for conservation, land capability classification has some disadvantages. The method in fact is confounding two activities: selecting the land use and deciding the suitability of the land for that use at the same time. This is all right when the possible land use is already known or fixed. It is less satisfactory when there are

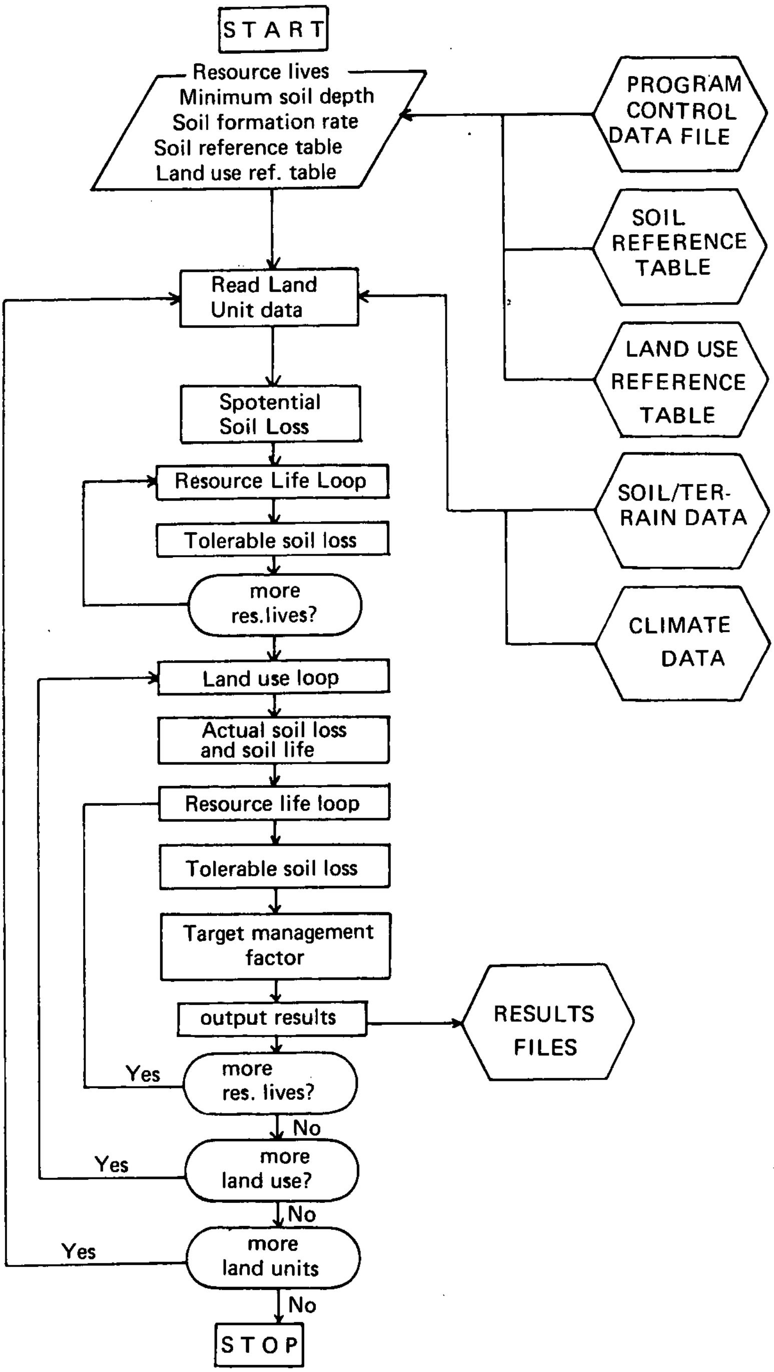
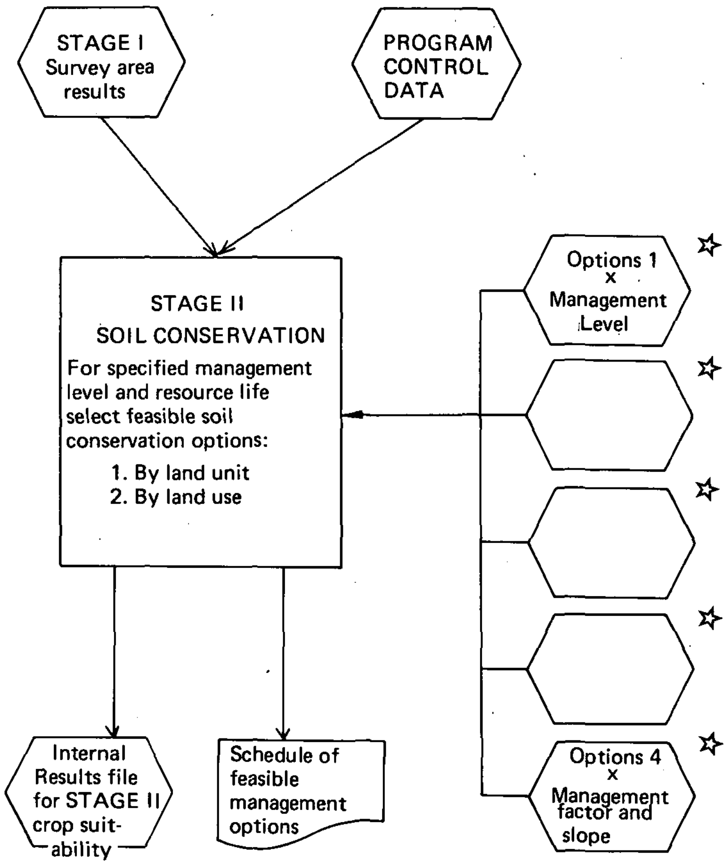


Figure 1.4 General logic flowchart of stage I soil degradation module.



Option soil conservation management practice option

✡ Reference Tables based-upon those given in Hamer, 1981

1. Table 10
2. Table 11
3. Table 14
4. Table 16
5. Table 17 and 18

Figure 1.5 Structure of the Iecs STAGE II soil conservation options module

various options available and the option selected depends on inputs which are made, which may be capital investment, or subsidies, or food-for-work labour inputs.

In practice the Land Capability Classificaton is intended for situations where the farmer is fully aware of his economic situation in a monetarized economy and has constant contact with, and confidence in, an active extension service and usually where there is land enough for choice in land use. This is rarely the situation of the farmers in developing countries, particularly those on marginal and inaccessible areas such as the hill lands. This point was well made by Bohlin and Messing (1981) and led them to recommend the FAO Framework approach to land evaluation for their conservation and land development work in Kenya.

The FAO framework and guidelines for land evaluation should avoid these difficulties since it proposes a procedure to select relevant land-use types and to indicate not only their physical suitability but also their economic viability on the land in question. Various criticisms have been made of the method, some of them ignoring the fact that the framework and guidelines are not instruction manuals. They are intended to be flexible and for users to select those methods which meet their needs; and to adapt them as required.

A valid comment is that the FAO method is complex. In fact the guidelines for Rainfed Agriculture is very complex as it is trying to offer guidance for all the myriad different conditions throughout the world. The reader should be selective: for instance no one will need all the land qualities listed, but having them as a checklist will prevent land evaluators overlooking any important features.

However it should be recognized that there is a trade-off between complexity and reliability. A preliminary estimate can be made by making use of only the simplest procedures described, but if more detailed and reliable estimates are needed the procedures will inevitably have to be more complicated. This is perhaps particularly so with the land-use requirements and limitations related to soil conservation.

The framework envisages not only physical evaluations but also economic, or quantitative, evaluation. This is particularly problematic where conservation is concerned. It is difficult enough to predict soil loss, but the economist is not concerned with soil loss itself but with the consequent loss of productivity, and converting one to the other is still a little explored subject.

Financial and economic analysis of soil conservation costs and benefits has many difficulties. The quantification of benefits is particularly difficult because soil conservation projects are multi-product and often very long term, it is difficult to assign monetary values to some benefits (or losses avoided) such as depletion of land where valuations are complicated by 'externalities' which distort land prices in relation to production. Benefits may therefore tend to be underestimated. Research is needed not only to predict yield reductions but also to find means to value land losses and deal with intergenerational benefits.

Furthermore the economic approach to conservation, judging its merit solely on costs and benefits, is not really adequate. It is treating land resources as a means to an end: production of tradeable goods. This is as if people who wanted to preserve tigers justified their activity because it provides increased facilities for tiger watchers. It may be more apt to treat the tigers or the land as ends in themselves. Economic analysis is useful and necessary for investment but it is not the only criterion. Putting the more philisophical and empirical elements into land evaluation for conservation has not been adequately dealt with as yet.

1.7 Land-use planning

The procedures for land-use planning are much less well documented than for land evaluation. There is even controversy over what should be included in the term, some practitioners regarding their task as confined to the physical design and lay-out of the land-use system and infrastructure – roads, conservation works, fields etc. At the other extreme are those who take land-use planning to mean the design of legislation to control the use of land. FAO has been developing guidelines for land-use planning in response to the needs of the developing countries, and intends to use the term in the broad sense covering the whole range of activities from legislation and extension work to physical assessment. Emphasis will be on the procedures for planning itself since that is where the gap is; there are sufficient books on how to collect information useful for land-use planning but few accounts of how to carry it out (some relevant ones are FAO 1971, Mollet 1984, OAS 1984, Corker 1983, Brammer 1979, Bennet and Thomas 1982).

An outline of the process of land-use planning is given in Figure 1.6 based on the simple thought sequence: what is the problem?; what are the possible solutions?; which is the best solution?; does it work?

Several features must be emphasized. Firstly land-use planning has to be carried out at different levels both geographically as shown in Figure 1.7, and functionally as suggested in Figure 1.8. It is important that the data collection, the intensity of study, the methods used and the presentation of results is opposite to the level of work.

Secondly the participation of the people who will be using the land must be secured. Otherwise they will not carry out the plans however well made. There are various publications dealing with this aspect (FAO, 1983 a, 1983 b).

Conservation is a part of land-use planning sometimes the most important part. Often to justify expenditure on the required conservation measures they must be securely inserted into the whole context of land-use, planning for land development.

Figure 1.6 Elements of the planning process.

Main stages	Elements
1. What is the problem, or objective?	1. identification of issues concerns and opportunities
	2. development of planning criteria
	3. inventory of basic data on resources and information on land use and land users
2. What are the alternatives?	4. evaluation of suitability of the land resources for specific land uses
	5. formulation of alternative plans (5, 6, 7 & 8 may use systems analysis
	6. estimate effects of alternatives
3. Which is the best alternative?	7. evaluation of alternatives (with participation of land users)
	8. selection of preferred alternative
	9. presentation of the plan (appropriately simplified for understanding)
	10. arrangements for implementing the plan. (administrative, legal, educational etc.)
4. How does it work in practice?	11. plan implementation
	12. monitoring the results (continuing data collection and research)
	13. evaluation of results
	14. amendments as required

Figure 1.7 Different levels and scales of land-use planning.

level	suggested scale range	operators
International (multinational; global; continental)	1:2 000 000 to 1:10 000 000	international agencies
National (large province)	1:500 000 to 1:1 000 000	planning ministry or division, assisted by technical divisions
Sub-national (administrative district or river catchment)	1:50 000 to 1: 250 000	land-use planning teams, collaborating with local administrators and technical staff
Village (farm; sub-catchment; small administrative unit)	1:5 000 to 1:50 000	land-use planner (government or non-government) working with local technicians, and land users

Level of Decision-making	To Accomplish	Example 1/
Objectives	Clarify ultimate desired	Sustained food production
Strategic planning	Decisions on main orientation of land use over the long term to achieve objectives	Reduce Land Loss by control of Land use and Land management
Policy planning	Decisions on method of achieving strategic aims	Provide guidance and assistance in conservation of soil, water and vegetation
Programme or Project planning	Tactical planning for implementation of policy by specified institutional arranf arrangement	Establishment of land use planning institutions and land resources conservation projects
Operational planning	Day to day planning of field implementation requirements	Organization of soil conservation extension teams, allocation of land for specific purposes, etc.

Figure 1.8 Levels of Decision-Making for Land Use Planning

1.8 Land evaluation as a management tool

This paper began by mentioning the four functions of production, land, labour, capital and management, and why it is important to evaluate the factor 'land'. Equally important for increased production is improvement in the factor 'management'.

Land evaluation, by providing a systematic way of predicting the results to be expected from management changes, is one way of improving managerial capabilities. It is an essential element in land-use planning which goes a step further, examines the options and systematically aids in the selection of the best alternative to meet the objectives of the land users.

However predictions of potential results and systematic selections of optimal solutions are only productive if they are made use of. Commonly however it is precisely the poor and disadvantaged hill dwellers, with low potential outputs per hectare, who are least able to adopt new management methods or invest capital and labour in conservation measures.

Land evaluation must therefore adapt to the social and economic conditions of the hilly lands (for example see FAO, 1983 a). Frequently it will be necessary to adapt, not the best solution, but merely the most practical solution for the local people even though this may mean less than adequate erosion control.

Fortunately the importance of environmental protection is becoming increasingly recognized and governments are more willing to provide the financial incentives to encourage hill farmers and other land users to do more to protect their land and to decrease downstream effects.

1.9 Conclusions

This paper has attempted neither to give a full account of the application of the FAO Framework, which might be superfluous in this company, nor to suggest the course which this workshop should take. Instead it paints the background with a broad brush and indicates some salient issues which may be addressed.

The subject is undoubtedly an important one which is causing increasing concern. The World Bank for instance is studying how it can better tackle the evaluation of conservation projects, which have tended to be neglected because of the inadequacy of cost-benefit analyses to indicate their real value. Yet all studies made, such as the FAO potential population supporting study (FAO, 1982), indicate that without adequate conservation the programmes for meeting the developing world's needs for food and fuel will be impossible to sustain.

Therefore it is to be hoped that this workshop can identify priority areas for concentration, priority needs for research, and will help to draw wider attention to the problem of conservation and motivate public and policy-makers to do more about it. On behalf of FAO, I wish every success to the work to be undertaken in the next few days.

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2 Erosion hazards and conservation needs as a function of land characteristics and land qualities

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2.1 Introduction

Establishing erosion hazards is a difficult undertaking as erosion is the result of many processes which influence each other in complex interactions and proceed at rates that vary with time and space. Most available assessment procedures are of a qualitative nature, based on a descriptive interpretation of the production environment. This approach has some obvious disadvantages: interpretations are only as good as the interpreter is who projects cause-effect relationships observed in other areas on a situation that is basically new to him. Reliance on personal experience is bound to make the evaluation of erosion hazards somewhat subjective and often inconsistent and irreproducible. To overcome these problems, mathematical relations have been suggested which relate observed or inferred land properties to soil loss. These relations are mostly regression equations; they lend the interpretation a quantitative appearance as their outcome is a figure instead of a qualitative class denotation. Planners, engineers and builders tend to prefer figures over less transparant qualitative erosion hazard indications in which the interpreter's doubts and reservations are so painfully present. It is questionable, however, whether this preference is justified when the figures result from a lumped parameter model, developed and calibrated for some other region, where the selection of relevant land properties was fixed just as their relative weights and the nature of interactive effects.

A qualitative assessment by an experienced erosion specialist is then more realistic and more reliable than results obtained with such abused 'simple models'. And if doubtful significance of results is the price for procedural consistency, then that price is too high.

What alternative do we have? If realistic and quantitative estimates of anticipated soil loss are to be made with standard procedures, the erosion process and its dynamics must be unravelled and described in a realistic and quantitative way. That is a difficult task involving the construction of event-oriented models of soil detachment (to establish the quantity of soil material potentially available for erosion at any time) and of overland flow/transport capacity (to determine how much soil is actually lost) in a regional setting. Years of methodological work will be needed to construct a comprehensive analytical – not just correlative – erosion model and, once it is completed and tested, its operational value will be reduced by its high requirement of accurate basic data. I think that we shall have to pass through this stage because only then can we hope to develop realistic 'simplified models' which would be useful in practical conservation work because of their limited complexity and data requirements. Such simplified models could offer the same advantages as promised by the 'simple models' that I have mentioned earlier but are vastly superior to them in that they have the perceptive basis and dynamic character required to describe erosion with some measure of accuracy.

The theme of this Workshop places the issue of soil erosion in the wider perspective of land evaluation. That is the only correct approach. Erosion involves a change in land properties and its assessment is part of any adequate description/evaluation of land. Therefore, though it is conceivable that land evaluators can, in some instances, ignore the possibility of soil erosion, a study of erosion hazards can never be realistic if detached from its land evaluation context. I have argued before that erosion, and its consequences for the environment, should preferably be described in a dynamic, quantitative way. For the very same reasons it is needed to explore the possibilities to give land evaluation a dynamic, quantitative basis. Considerable modelling work has already been done on the productive capacity of lands with a long history of agricultural use. As methodological work advances, the models developed become ever better equipped to deal with more complex situations such as exist in newly reclaimed lands and in (sloping) areas where erosion is a potential danger. In the second stage of a 'two stage land evaluation procedure', the productivity analysis can then be complemented with a socio-economic analysis in order to decide whether what is technically feasible is also economically attractive and socially acceptable. In the past, the Framework for Land Evaluation (FAO, 1976) has helped enormously to structure our thinking on the most desirable procedure of land evaluation. The principles, definitions and concepts put forward in the Framework will be equally useful in quantitative land evaluation. Land qualities, in particular are pivotal in the process of integrating soil loss (and associated conservation needs) into the land productivity analysis. A possible strategy for this integration will be outlined in the following.

2.2 Integrated erosion analysis

Erosion modifies the productive capacity of land. If the seriousness of erosion, and therewith the need for conservation measures, is to be made explicit, the initial productive capacity of a land-use system (Beek, 1978) must be known as well as the effect of erosion on this productive capacity. Consider the following train of thought:

1. Land productivity is described at the level of the land-use system, (LUS) i.e. as a function of both the land use (type) and the land (unit).
2. Erosion, quantified as soil loss over time, is described as a function of the properties and dynamics of the LUS
3. Conservation needs are (described as) sets of measures which curb or correct erosion-induced modifications of land characteristics and qualities to such extent that LUS-productivity is maintained at an acceptable level.

2.3 LUS; productivity

It was said before that the principles, definitions and concepts put forward in the Framework for Land Evaluation are also useful to quantitative land evaluation. Implicitly, this holds also for the LUS-productivity assessment – which is part of the land evaluation procedure – but considerations of a practical nature force us to use some Framework concepts in a somewhat unconventional way. In particular, this pertains to the treatment of present or projected land use. A 'Land-Use Type' (LUT) is described by a number of 'key attributes' which reflect those biological, socio-economic, technical, etc. aspects of the production environment that are relevant to the productive capacity of the LUS. It is as yet not well possible to handle many key attributes simultaneously in a dynamic way. Therefore, crop selection is taken as the main attribute which characterizes land use. The other key attributes are simply compared with fixed boundary values to judge the scope for land management measures. If, for instance, the availability of farm power and implements is low, then it is unrealistic to consider high technology measures such as sprinkler irrigation. It follows that the dynamic LUS-productivity analysis is done for a combination of one Land Unit (characterized by a set of basic land characteristics) and one crop ('commodity'). This analysis forms the nucleus of a quantitative land evaluation exercise. The combination of one Land Unit, one commodity and a fixed set of management boundaries represents a single land-use system. Multiple systems, i.e. more than one crop on the same field at the same time, can be handled by combining single LUS-analyses, taking into account the effects exerted on the crops by each other (competition for light, water, nutrients, etc.). Compound systems are created as concentrations of single and/or multiple systems. The productive capacity of a Farming System is analyzed – in line with the philosophy of the Framework – by considering combinations of individual LUS-productivity analyses.

It is perhaps useful to stress here that the quality deliberations made earlier with regard to erosion descriptions apply also to the LUS-productivity analysis with which the erosion analysis is to be connected. There are striking parallelisms between the practical difficulties encountered in the construction of erosion models and those met when describing LUS-performance. Not surprisingly, the solutions which have been proposed in terms of regression-based 'simple models' have a familiar appearance. Such models predict productivity, in absolute or relative terms, on the basis of a limited number of land characteristics and qualities that are hidden in black boxes and interact in a linear multiplicative or additive way. Weighting or calibration factors are added to provide couleur locale and an attractive regression coefficient. Last but not least, 'simple' productivity models have in common with 'simple' erosion models that their indiscriminate use in regions other than those for which they were developed leads to gross inaccuracies and misinterpretations. A realistic and universally applicable LUS-productivity model cannot be simple. It can, perhaps, be a simplified version of a comprehensive model. In any case, it must – commensurate with the amount of detail and accuracy pursued by the user – contain more or less elaborate, dynamic descriptions of relevant land qualities and account for their direct and indirect effects on LUS-productivity.

2.4 LUS-properties and erosion

For a static description of land, one refers to its observable characteristics. Such characteristics can be single or compound. Examples of single land characteristics are average total rainfall, slope, soil depth, etc. Compound land characteristics are combined/

intertwined single characteristics; examples are the moisture holding capacity or the saturated hydraulic conductivity of the soil. Of course, land characteristics influence the dynamic behaviour of a LUS, but not necessarily all land characteristics do so in a certain LUS and not all work in the same way. It is therefore attractive to aggregate (the workings of) those land characteristics which, together, cover a basic requirement of land use and thus influence LUS-productivity more or less independent of other land characteristics or aggregations of land characteristics. Counter to the opinion of some Framework exegetes, I consider such dynamic clusters of interacting land characteristics as land qualities. An example of such a land quality would be the quality 'moisture supply to a crop', influenced by single land characteristics such as rainfall and potential evapotranspiration, and compound land characteristics such as the soil moisure capacity, and by interactions between them.

Many of the land qualities that have a direct bearing on LUS-performance are also relevant in erosion analyses. Consider aain the land quality 'water availability to a crop'. In crop production models this quality is described by quantifying water supply to and losses from the root zone during short time intervals with assumed steady state conditions. When the analysis of one time interval is completed, both exogenous and endogenous LUS-characteristics are adjusted to represent the state of the system over the next time interval. The procedure is repeated for so many intervals as the crop cycle(s) contain. Estimates of excess surface water supply over time are generated in the process and present a quantitative and dynamic description of surface storage and runoff. There are similar links between the descriptions of rainfall distribution/intensity and of physical soil properties in het LUS-productivity analysis and the quantification of kinetic rainfall energy and soil (structure) stability as needed for the analysis of soil detachment and splash erosion. In other words not only can the description of soil erosion be hinged into the LUS-productivity analysis but there can even be complete integration of the two.

2.5 Erosion and the need for conservation measures

The quantification of soil loss in the context of dynamic LUS-behaviour is a first and indispensable step towards sound soil conservation. Whether erosion control measures are actually taken depends not only on the rate and quantity of soil loss but is also policy-determined. One could, for instance, ignore the soil loss altogether, or – the other extreme – strive for zero loss. More commonly, a 'tolerable soil loss' boundary is set, e.g. lower than or equal to the new formation of soil trough pedogenesis. It is doubtful whether a quantity criterion alone can in practice be satisfactory. Surface soil lost through erosion has normally higher nutrient and organic matter contents and better physical properties than subsoil material. LUS-productivity is, in a way, an indicator of the compounded agricultural quality of land. Consequently, 'tolerable soil loss' is often expressed as the soil loss which is associated with a certain drop in LUS-productivity over a certain period of time. The actual values of the acceptable drop in productivity and of a realistic planning horizon are subjects of continuing debate. We best leave these issues to Policy Makers and (Land Use) Planners whose possible motives will not be discussed in any detail here as they are partly of a sociological, economic, cultural and/or political nature and placed outside the scope of this presentation. Let us regard the 'tolerable productivity loss' – boundary as an exogenous datum although we are aware that we have here stumbled upon one of the several points of contact that exist between the first (physical) stage and the second (non-physical) stage of the land evaluation procedure, a point where both stages could interact in an iterative Farming Systems analysis.

The use of a boundary value for tolerable drop in LUS-productivity implies that control measures are not so much regarded as means to reduce soil loss but first and foremost as means to preserve an acceptable level of LUS-productivity over a defined period of time. If control measures are also taken on other grounds, e.g. to protect infrastructure, a tolerable soil loss limit can be set exogenously in addition to the LUS productivity loss boundary. Both boundary values have then to be observed in the analysis. We shall disregard this possibility in this discussion and concentrate our attention on the quantification of the relation between erosion control and LUS-productivity.

2.6 Conservation measures affect LUS-characteristics

In this section, the loop 'LUS-characteristics → erosion → control measures → LUS-characteristics' is closed and therewith the feedback is established that is necessary to keep a generated need for conservation measures within realistic proportions. Conservation measures can affect any of the two components of a LUS: they can affect the use (type) and also the land (unit). It is not possible to give here an exhaustive inventor of imaginable erosion control measures and their effects on LUS-dynamics but the following example may be illustrative:

A measure which manipulates land use could be an increased use of fertilizers. The resulting higher uptake of nutrients induces more luxuriant lea row over time, quantified in the LUS-productivity analysis. This increases the interception of rain drops and decreases the soil detachment/splash erosion figures generated in the erosion analysis. As a consequence, inherent soil fertility is preserved which, in turn, reduces the fertilizer requirements (the quenching effect of the feedback) needed to maintain the minimum LUS-productivity.

Measures which alter land (unit) characteristics and qualities have often a more permanent character than measures affecting land use. Feedback effects may then not immediately be recognized as such but are certainly in operation. For instance, land levelling performed once makes levelling an irrelevant control measure for a large number of years.

2.7 The role of land characteristics/qualities

In the LUS-productivity analysis, the momentary sufficiency of a quality is judged against the momentary requirement of the land use-type/commodity with regard to that quality. Consequently, the analysis consists essentially of a repeated comparison of dynamic commodity requirements and dynamic land qualities. The land characteristics are basic data which are input in the requirement and quality descriptions.

The importance of accurate and reliable basic data cannot be overemphasized: the quality of the analysis results can never surpass the quality of the basic data on which the analysis is founded. The analysis itself does not add any new information on LUS-productivity, erosion hazards or the effects of conservation measures. It solely makes the consequences of the analyst's basic data selection visible. Poor, i.e. incomplete and/or inaccurate, basic data give poor evaluation results, a rule which applies equally to quantitative and qualitative evaluations. There is definitely a need for more efficient collection, more rigid screening and more accessible storage/management of basic information on land and its use. The means to meet this need become increasingly available: data collection, e.g. remote sensing, and handling techniques become more and more sophisticated, computer (memory) princes have nosedived over the past years and awareness of the possibilities of mechanized data handling has increased. As a result, data banks and soil/geo-information systems are now being developed by (conglomerations of) research institutions with foresight. The recent initiation of ISRIC, the International Soil Reference and Information Centre in Wageningen, is a significant step in the right direction.

Better data availability makes the development of better data interpretation procedures a realistic undertaking. An example is the dynamic LUS-productivity model developed by the Centre for World Food Studies in Wageningen (Van Keulen and Wolf, 1985). This model was intended to be the spine of a quantitative land evaluation procedure from the moment of its conception and is set up in such a way that maximum benefit is obtained from the basic data and experimental results published by agronomic research (institutes). The Centres LUS-productivity model consists basically of a string of submodels, each evaluating the influence of one land quality on LUS-performance. The individual submodels are arranged in a hierarchical following order. Their inner structure will not be discussed here but the philosophy of dynamic LUS-modelling and the role of land quality descriptions in the analysis procedure deserve attention. Consider the following arrangement:

	LUS-productivity analysis		
	Land Quality Descriptions:		Commodity Requirement Descriptions:
1st (highest) level	Availability of Solar Irradiance	↔	Energy Requirement (+ temperature range)
↓			
2nd level	Availability of Water	↔	Max. Transpiration Rate
↓			
3rd level	Availability of Nutrients	↔	Minimum Nutrient Concentration of Tissue
↓			
4th level	'Another Land Quality'	↔	Corresponding Requirements
↓			
5th level	etc.		
↓			
etc.			

At the highest level of the LUS-productivity analysis it is assumed that all lower level land qualities satisfy the related commodity requirements. LUS-productivity is then limited by the availability of solar irradiance only (within the capacity of the photosynthetic mechanism of the crop at the prevailing temperature). The calculated productivity is the highest that can be obtained in practice. At the second hierarchical level in the analysis procedure, actual soil moisture availability is compared with the crop's water requirement. The availability of nutrients (3rd level) is still assumed optimal. If soil moisture availability is suboptimal, this affects LUS-productivity. The calculated productivity is then lower than the value established for level 1. At which level the LUS-productivity analysis is done depends on the user. The more land qualities are included in the analysis, the higher the data requirement is, but the closer the resemblance between simulated LUS-productivity and actual (measured) LUS-performance. The analysis is done for short (typically 1 day) time intervals and repeated for the duration of the crop cycle(s) under investigation. Interactions among quality-requirement combinations positioned at different hierarchical levels is achieved through endogenous variable adjustment at the end of the calculations for each interval. For instance, crop growth during a given interval modifies the capacity to intercept solar irradiance (1st level), and the capacity to transpire (2nd level), and the nutrient requirement (3nd level), etc. during the next interval. Similarly, the effect of exogenous 'forcing' variables such as rainfall or fertilizer inputs, is felt at all levels considered in the LUS-productivity analysis.

It will need no further argumentation that the dynamic description of land qualities is a vital part of realistic LUS-productivity assessment. It will also be clear that such descriptions allow to integrate soil loss analysis in the land evaluation procedure and to assess quantitatively the effect of conservation measures on land qualities and thus on LUS-productivity.

2.8 Some additional remarks

What has been said in the foregoing may inadvertently have given the impression that land evaluation is not to be taken seriously unless it is computerized and free of artistic ad hoc deliberations that are founded on something as vague as 'experience'. That notion is definitely wrong. It was merely argued that mechanized data interpretation has – under conditions that permit its use – the advantages of procedural consistency and a quantitative basis. Consistency of procedure is a practical necessity; blind reliance on it is dangerous. Our German friends with their record for procedural thoroughness say it with clarity: 'Jede Konsequenz führt zum Teufel'. Simulation model results mean nothing unless examined and approved by the land evaluator. No matter how sophisticated a mechanized interpretation procedure may be, it is never a substitute for experience.

What has been said in the foregoing was meant to illustrate the importance of land characteristics and land qualities for erosion and conservation analyses. I have placed this discussion within the wider frame of quantitative land evaluation but it was never my intention to suggest a ready-to-use recipe for 'QLE'. The pathway shown may have its merits but it is sadly incomplete; such vital aspects as regionalization of the analysis, reconciliation of the physical boundaries recognized in LUS-productivity analysis and the policy, cultural, etc. boundaries relevant to socio-economic analysis, description and possible substitution of physical inputs and/or labour needs, and many more, remained undiscussed.

What has been said in the foregoing shows that there is no fundamental discrepancy between our past attainments with regard to land evaluation methodology and QLE. On the contrary, Framework concepts and definitions are fully applicable. The results of mechanized interpretation procedures may not strike any land evaluators as impressive yet. Allegorically, I may perhaps refer to the many people who, in the early days of motorization, saw no future for motorcars because the first models were easily outrun by the horse. They have later revised their opinion. The inherent possibilities of mechanized data interpretation are such that a similar development may be expected here. In the future, experience in computerized data management and interpretation procedures will be asked in addition to a record of proven field experience. That development has been set in motion. We cannot close our eyes to it.

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Summary discussion

Burrough: The propagation of errors must be considered when we speak of input; the resulting error may be larger than the individual one when we for example think of the parameters used in USLE.
Driessen: True

Bennema: What kind of data are being put in and what are the assumptions about the input; what kind of meaning does the quantitative data base has; erosion is a permanent process, the loss of soil productivity can be calculated for 5, 10 or 15 years; the time period taken for the study is very important as losses may increase the longer the process, continues.
Driessen: No time horizon is mentioned nor set, but it certainly will take some time to develop methodology, we are not even sure how this problem can be solved,

Flach: The accumulation of errors is also an advantage in finding the errors in the model; thus run the model and see if impossible values are obtained,
Driessen: True, if you want to see if there are any fish in the pond you have to try to catch them.

3 Sloping land: soil erosion problems and soil conservation requirements

D.W. Sanders

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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.

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

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.

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

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 understimated; these are length of slope, shape, roughness and aspect.

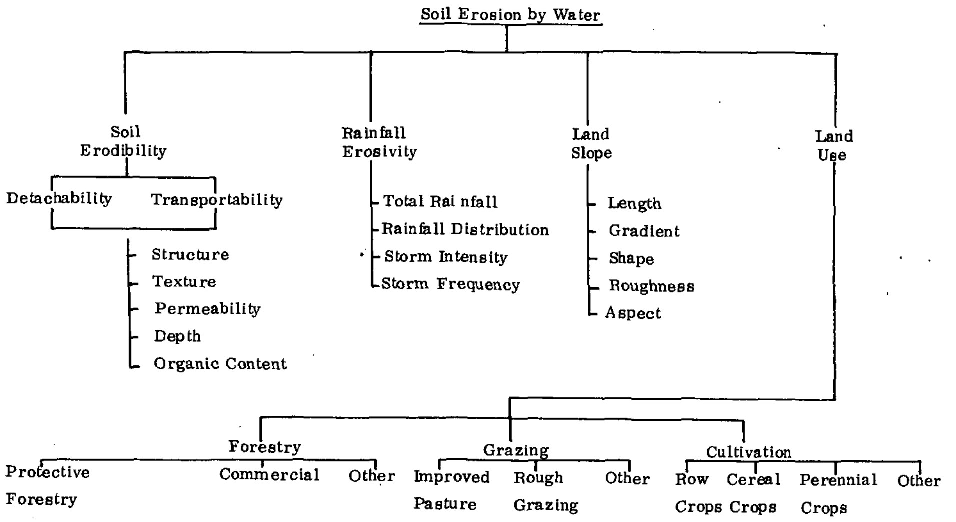

Figure 3.1 Soil Erosion by Water.

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 countries, 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?

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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.

4 Resources for the future: measuring and managing of the ultimate limit to growth

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4.1 Introduction

Mr Rector, members of the council, ladies and gentlemen, fellow students. My immediate pleasure at being asked to give the Schermerhorn Lecture was rapidly superseded – after I had accepted – by a great sense of inadequacy. I was appalled at my temerity in accepting the invitation. It was not that I was over-awed by the list of my illustrious predecessors, but rather by the sheer technical competence of the audience I was required to address. What could I say to an ITC audience on the use of survey techniques that they did not already know? The prospect was daunting.

On the problems presented by the growing population of the Earth, there was nothing I could say that has not already been said to you by the leaders of the various United Nations organizations specifically designed for the task. Accepting that the Earth has problems, I look instead at what – by better measurement and better management – we can do about them. For this I shall call on some of the results of my colleagues in CSIRO that could be relevant to the work of ITC in measuring the way mankind is using what is the ultimate limit to growth – the land areas of the world. Then, in the light of my more recent studies, to see what can be done to manage these resources more fruitfully.

This institute, ITC, in the course of the 30 years of its existence, has become a world renowned centre for teaching the technique of survey in all its forms, and particularly for the courses it has given to students from what we call the developing world – parts of which, we should remember, have a developed history twice as long as our own.

Your work, sirs, in showing how to measure – and in measuring the areas of land put to different uses – will be needed to an increasing extent to follow changes that are occurring, and ultimately to provide a basis for better management.

Broadly speaking, man needs land for six purposes:

(1) to grow crops for food and fibre,
(2) for grazing for his domestic animals,
(3) to grow trees for timber,
(4) for houses, factories, mines and transport,
(5) for recreation, and
(6) for the collection of water, and the conversion of rainfall into a usable water resource.

More recently, a seventh need has been added for the creation of biosphere reserves – but it remains to be seen whether, at the present rate of population growth, man can afford such luxury.

Of these uses of land, the first three – pastures, cropland and forests – are all mutually interchangeable, subject only to the restrictions of climate. The use of land for recreation or for biosphere reserves can also be changed to the first three uses if there is reason enough. Land can be used for all these purposes and still fulfil the sixth use – that of collecting rainfall and converting it to water. When land is used for urban developments, however, largely covered by bricks and mortar, concrete and tarmacadam, to all intents and purposes it is lost forever for the growth of plants, although it can still be used as a catchment for rainwater.

We can anticipate that if we progressively raise the level of production per hectare in the developing world to that of the developed world, as should be the result of the courses given at ITC and Wageningen, we could feed twice the population from the area cultivated at present or, as Professor Buringh has suggested, an even larger population. An inevitable fact of this larger population, however, is that the people must have somewhere to live. Stacking them on top of another in tall blocks of flats does nothing to diminish the area of land needed for transport, industry or recreation. The conflict remains.

The use of aerial photographs and Landsat images to delineate the boundaries of forests, urban development, irrigated areas and cropland are now well-established techniques, and well taught at ITC. Occasionally their use procedures surprises. When the LACIE (Large Area Crop Inventories Experiment) programme was being extended to Australia, the researchers were amazed to find a patch of country showing the signature for wheat appearing in the arid West Darling region, with annual rainfall of approximately 150 mm. Wheat was being grown on the bed of Lake Tandou, one of the shallow lakes filled intermittently by the overflow from the Darling River, and when the researchers turned up at the property, a vast sheep station, the farmer wanted to know how they knew it was there. The spy in the sky can be very effective.

4.2 Measurement and management in urban areas

Because the land area of the Earth is the ultimate limit to growth, its management in the densely populated urban areas is particularly important. Holland has a long history of increasing its land area by reclamation from the sea, and nowhere else in the world has this process been carried out so extensively or so successfully. Elsewhere, changes in the coastline have occurred as a result of man's activities, and it is necessary to measure the changes in order to learn how to manage them.

Aerial photographs and Landsat images are particularly effective in following changes and can provide, with appropriate ground truth, the information necessary for management. The Le Fevre Peninsula, part of metropolitan Adelaide, provides an example. It lies on the eastern coast of the Gulf of St Vincent where the city of Adelaide was founded 149 years ago, and is protected by sand barriers thrown up by the tides. With the greatly expanding population of the post-war period demanding more recreational facilities, groynes and boat harbours have been constructed. These have interfered with previously established patterns of interaction between sea and land and quite suddenly the beaches and sand barriers began to disappear.

Aerial survey of the area showed that the peninsula is built up of series of dunes, progressing northwards and curving eastwards. Each dune carries a shell layer. The shape of the dunes was determined by deep augering [3]. Longitudinal and transverse sections were prepared and the time of deposition of each dune was calculated from the age of the shells, duly corrected for the residence time factor of the southern ocean [2].

The oldest dunes were formed 7,000 years ago – that is about the same time that the ice sheet was retreating from Stockholm, and perhaps 30,000 years after the aborigines arrived in Australia. From the cross and transverse section, it was possible to calculate the quantity of sand transported every 100 years, or every year. With this information, the problem of the disappearing sand barriers of the coast can be solved by carting sand from the northern parts and depositing it on the southern beaches. The tides then do the rest. Measure and manage!

4.3 Measurements and management in semi-arid areas

At the other end of the population spectrum are the semi-arid lands of the world. Many environmentalists consider these to be the world's major problem areas, with wind erosion and desertification destroying once fertile land. A hunting lodge in Jordan, for example, is now surrounded by desert, whereas when it was built the country around was savanna and abounded in game, still pictured on the walls.

A commonly suggested solution to the problem is to attempt to reduce the pressure of population and to avoid the use of this fragile ecosystem. I would take a different view. The semi-arid lands are perhaps the largest under-used soil asset the world possesses. Measurement might allow us to manage these areas.

One such area is the western division of New South Wales which receives on average 80 to 250 mm of rain a year. Averages, however, mean nothing, since the rainfall may stay at 12 to 24 mm for several years, and the next year go to 700 or 800 mm. The deep rooted shrubs – blue bush (*Kochia* spp) and salt bush (*Atripex nummularia*, etc) – which constitute the dominants of the shrub steppe are the only plants that survive from year to year. Overgrazing destroys this cover, and makes the vegetation less able to respond to the light occasional rains.

Figure 4.1 shows the difference along a boundary fence. This difference in vegetative cover shows up in Landsat images and allows us to measure the areas at risk from wind erosion. With this information available and a knowledge of the numbers of sheep kept in the different areas, it is possible to plan the management of the grazing that will give optimum stocking consistent with the maintenance of vegetative cover.

Much of the land in this low rainfall country has been piled into long banks of sand, the so-called 'seif dunes', separated by inter-dune corridors or swales in which the surface soil contains many fine particles. The dunes may extend for 100 km or more, approximately in the direction of the prevailing winds. In the Sahara and the Arabian deserts, the seif dunes are generally without vegetation, but in the Australian deserts they are more often vegetated. The difference is probably due to the fact that the Australian aborigines had no domesticated flocks of grazing animals. This vegetation is tremendously important, and its maintenance has a cummulative effect on the soil.

It is generally appreciated that the velocity of the wind increases logarithmically with height above ground, so one might expect that the wind velocity on the crests of the dunes would be much higher than it is in the intervening swales. The wind velocities measured simultaneously from dune-to-crest on dunes at Fort Grey in the north of the western division show this increase in velocity at all sites [10]. On the

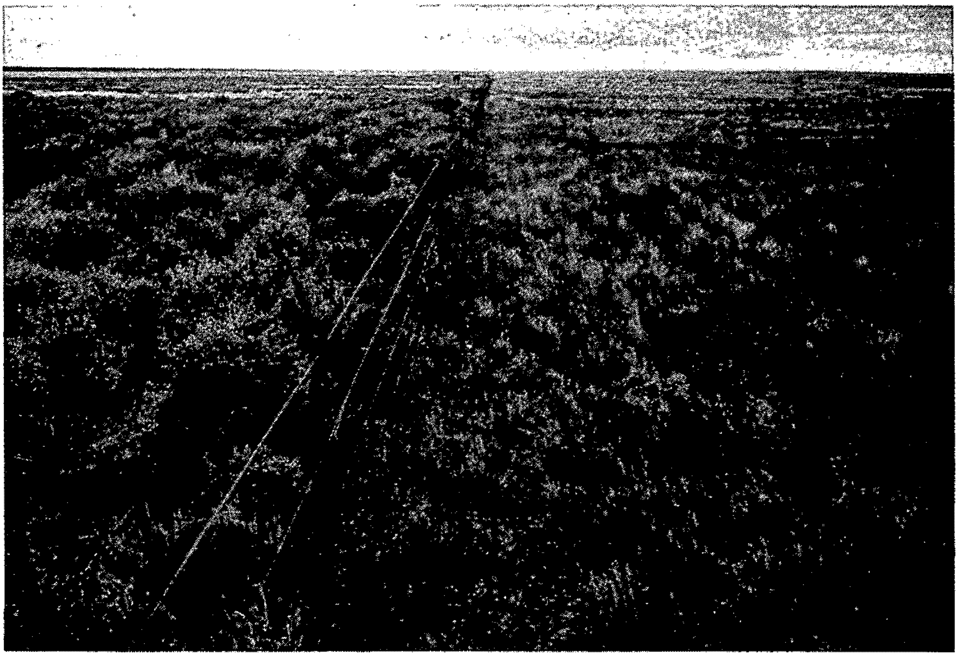

Figure 4.1 Saltbush, overgrazed (right) and protected (left) west of Broken Hill, NSW (photo by D.Gratz)

bare crests, the velocities even 10 cm above ground level are still relatively high. At Lake Popiltah, however, although the wind velocity over the crest 2 m above ground is much higher than 2 m over the swales, the presence of the quite small amount of vegetation on the dune crest has reduced the velocity of the wind at the soil surface to less than what it was on the crest at Fort Grey, and also less than it was on the vegetation-free patches of the swales at Popiltah. There is a concomitant increase in the quantity of fine particles in the soils of the crest.

If my view is correct, and we shall need in the future to farm the semi-arid lands of the world much more intensively than we do now, the management of the vegetative cover will be of paramount importance. A measurement tool similar to that developed at ITC for forest mapping and forest inventory might be the answer.

It needs to be emphasized that the changes in the topsoil are relatively rapid. In central western New South Wales, a large area of land covered by 'mallee' (*Eucalyptus oleosa, E dumosa*) – small trees that formed a flow woodland – was cleared for growing wheat under soldier settlement schemes at the end of World War I. We found by sampling on a one chain grid, *ie*, approximately every 20 m, that the clay and silt content of the topsoil diminished continuously as we moved leeward from the edge of the uncleared mallee, and 166 m away from the tree belt 80 per cent of the silt and clay had been lost in less than 25 years.

The soils of both the dunes and the inter-dune corridors have been formed by the same soilforming process – a fact which makes nonsense of some systems of classification because the farmer has to cope with both types of soil in one paddock. He generally ploughs and seeds across the whole sequence, using the same seed and fertilizer mixture. Usually the growth on the dune crest is less than on the flanks and in the swales, and in a low rainfall year the ridge may suffer from wind erosion and lose some of its finer material.

To appreciate the possibilities for development, we need to learn how to measure the extent of such a country, and then to develop appropriate management techniques if the areas concerned are large enough and the responses expected appear to be great enough.

The difference is caused not only by water deficit on the dune crests. The coarser nature of the material of the crests has allowed more intense weathering, and we find that the crops on the ridges respond to an input of trace elements [6]. If we apply a different fertilizer mixture to the ridges than to the swales, not only do we get a better yield overall, but because of the increased stubble (if wheat or barley is being grown) there is a reduction in the susceptibility to wind erosion, with the consequent possibility of extending cropping to areas of lower rainfall without damaging the soil.

Before such an area can be managed effectively, it is necessary to see if the demand is sufficient to justify the production of a separate fertilizer mixture (Cartwright [6] has shown recently that the major deficiency is zinc, and he has mapped the distribution of the zinc-deficient sites on the Eyre Peninsula). It is possible to measure the extent of the dune crests using Landsat images, and to find – as a result – that in this part of the semi-arid zone 27 per cent of the area requires a different fertilizer mixture – a demand sufficiently large to persuade the fertilizer manufacturers to produce one.

4.4 Other growth restrictions of the semi-arid lands

4.4.1 Phosphate deficiency

The soils of the semi-arid parts of the world, as well as suffering from a nutrient deficiency as described above, may also suffer growth restraints caused by toxic or deficiency levels in the sub-soil; in coarse textured soils, there may also be fungal attacks. Not all soils of the semi-arid lands of the world show the same pattern of nutrient deficiency. In the low rainfall areas of the Palouse country of Washington state (northwestern United States), excellent crops of wheat can be grown in areas with rainfall of less than 200 mm a year. The practice is to grow wheat every other year and to keep a weed-free fallow the next. This allows the rain received in the crop-free year to accumulate in the subsoil and to be drawn on by the following wheat crop. We have tried exactly the same system in southern Australia, and generally it has been a failure.

The difference seems to lie in the nutrient levels. In the Palouse, the soil is derived from loess, rich in available phosphare, with levels ranging around 20 to 25 ppm to depths of 7 or 8 m. By contrast, the South Australia soils, developed on an ancient land surface, are grossly deficient in available phosphate. Most of what is present has been applied as fertilizer in the last 100 years and is concentrated in the surface soil.

The moisture content and root distribution at two times of the year of a solonised brown soil [13] were compared with the profile of available phosphate [9]. The roots had stopped growing even when available water was still present in the subsoil, while they retracted in the dry topsoil. The data suggest that unless available phosphate (in this case) is present in the horizons where water is also present, the roots cannot continue to grow very far. In the Palouse, however, the available phosphate is present right through the potential root range, and the soluble introgenus fertilizer applied to the wheat crop by the farmers goes down into the profile wherever it is taken by the percolating water from the rains. The pattern observed in South Australia appears to hold in the soils of other old land surfaces, such as Jordan, but does not occur on soils derived from loess or from some types of volcanic ash.

I calculated that if there was a water soluble phosphatic fertilizer available that could be carried down the profile with the rain, without being fixed to the sesquioxides, etc, it would increase the potential wheat belt of Australia by between 15 and 25 million hectares.

Subsoil data for the peri-Sahelian regions is at present lacking, but if investigations showed a similar pattern occurring, the techniques of survey taught at ITC would allow definition of the areas potentially capable of development in this tragically troubled zone of the world.

4.4.2 Boron toxicity

In wheat and barley, boron toxicity manifests itself as patches of white tissue in the leaves. These result in reduced growth and, in severe cases, in the almost complete collapse of the plant [5]. In glass greenhouses, barley plants containing over 20 ppm at the boot stage show clear symptoms of toxicity. According to Gupta [8], anything over 15 ppm in the plant at boot stage is indicative of toxicity, but many South Australian barleys contain up to 300 ppm and may still be growing.

Boron toxicity seems to occur most commonly on the sodic soils which are so widespread in Southern Australia but to date it has not been possible to develop a technique for determining by aerial survey the areas on which boron toxicity is present. An extended survey of the boron content of Australian barly is at present underway to locate the problem areas and perhaps discover a signature that can be used for aerial survey [6].

There appears to be a marked varietal effect. Cultivators that have been bred on soils with a high boron content in the subsoil are clearly more tolerant to high boron levels when grown elsewhere. Halberd, a wheat bred at Roseworthy College on soils with a high boron content in the subsoil, is relatively resistant to boron toxicity, while Akka, bred in Holland on non-boron toxic soils, is an almost complete failure. Such varietal differences probably explain the low levels of boron considered to be toxic by Gupta.

4.4.3 Soil-borne disease

In the National Soil Fertility Project undertaken in Australia a few years ago, we found the variation in yield among the plots receiving high levels of fertilizer to be as great as those between the plots receiving high levels and those receiving none. Aerial photography showed that the patches of bad growth appeared in roughly the same position in the field from year to year, even though the crops differed. The differences were caused by infection with fungi or nematodes, but the pathogens attacking the wheat were not the same as those attacking the barley, which were different again from those on the medics with which the barley was undersown. The development of the pathogen attack is clearly related to either the physical or chemical condition of the soil.

In further work, Rovira [11] has shown that most of the wheats bred in favourable conditions on the experimental farms of South Australia are susceptible to eelworm attack. In contrast, one wheat – Festiguay, which has not appeared in official Department of Agriculture recommendations for years – is highly resistant to the eelworm. Growing a crop of Festiguay wheat consequently results in a marked reduction of the numbers of eelworm cysts. Festiguay wheat, outyielded by 15 to 20 per cent by other wheats in good soil conditions in departmental trials, can outyield them all by 100 per cent in soils with a high eelworm burden.

The varietal differences in their reactions to different soil conditions provide a justification for the creation of the newly established international research organization, the International Board for Soil Research and Management (IBSRAM).

Inevitably the international centres for agricultural research are developing cultivars which grow and yield best under the soil conditions and soil management practices of the research stations themselves. Their performances need to be measured on different soils and under different management conditions before it is known how far their superiority extends.

A closer look also needs to be taken at the performance of the cultivars grown under the more severe conditions of subsistence agriculture before an attempt is made to substitute a variety that performs much better, but under better conditions. Festiguay wheat is one example, while some of the old maize cultivars collected recently in Mexico by the Institute for Renewable Biotic Resources at Xalapa may provide another.

4.5 The camera cannot lie?

In utilizing the aerial survey approach, the work and training programmes at ITC have often emphasized the need for ground truth to check the validity of the conclusions. How essential this is can be seen from the work at Cooloola on the central coast of Queensland, Australia [14]. Aerial photographs of the forest cover on the dunes indicates that the forest might be expected to prevent erosion. On inspecting the situation under the trees, however, it was obvious that sand was being moved. Sand traps installed showed a movement of 3.25 to 9 litres per metre per year, and the effect could be easily seen in the exposed roots of the trees. Although the dunes had been windpiled, and some of the erosion was caused by wind, a large part of the movement was caused by raindrop splash. Unexpectedly, this was more serious under the rainforest than under the schlerophyll forest, despite the closer canopy of the rainforest. The effect appeared to be caused by the greater height of the trees in the rainforest, which meant that the drops falling from the branches had a greater terminal velocity of fall, and hence a greater energy which was dissipated in the splash. Thus it would not seem possible to assume that a good canopy means no erosion; other details need to be taken into account.

4.6 Measure and manage – the tropical forest

Tropical forests have probably been the subject of more debate than any other topic of contemporary ecology, and those who want to cut down the forests – particularly the forests of the Amazon – are castigated as exploiters without a thought or care for the rare biological species present in them, or for the damage that cutting down those forests might do to the world's climate.

One thing in certain: with Landsat images we can now measure precisely the boundaries of the forest and hence the area and condition of what remains. Indeed, one of the ITC programmes has as its aim the estimation of site quality. In the predominantly coniferous forests of Canada, we can see quite easily on Landsat images not only the boundary of the forest but also the recently cut-over forest and the re-growth areas. In tropical northern Australia, it is possible to measure the distribution and area of the three main types of forest. My Brazilian colleagues tell me that it is possible with Landsat images to show that to date they have cleared only 1.75 per cent of the forests of the Brazilian Amazon.

If the deforestation of the Amazon continues at the present or an enhanced rate, will this affect the climate? The answer is 'no' and 'yes'. The idea that the Amazon forest is one of the 'lungs of the earth' is nonsense; in an article in *The New Scientist*, 1972, Monteith pointed out that since the Amazon forests are mature forest they can, by definition, absorb no more carbon dioxide than they exhale or release no more oxygen than they absorb.

With regard to rainfall, the answer is different. From the results obtained by Salati and his colleagues [12], it seems likely that over much of the Amazon basin between 60 and 80 per cent of the rain that falls has been recycled to the atmosphere from the water in the ground by evaporation from the trees. If the land were cleared of trees and planted to crops and grass, would the situation be any different? Where the available water in the root zone remained high, the shallow rooted crops and grasses would probably evaporate as much water as the original forest. In the drier parts of the basin, however, the shallower-rooted annuals would not be able to pump into the atmosphere as much water as the deeper rooted trees. More of the rain that fell would drain to the rivers and probably out of that immediate area. Two things would follow: the area concerned would receive a smaller proportion of its rainfall from water transpired by the crop, while – since the leaf area of the annuals would dry out more rapidly than that of the trees – the area would have a higher albedo and the quantity of rain received would be likely to diminish.

Should the threat of a decline in the rainfall of the Amazon basin inhibit the government of Brazil from any further clearing of the forests of the Amazon? Not if Brazil is a signatory to the United Nations World Soil Charter (1982), for each signatory undertakes that it will 'utilize its soil on the basis of sound principles of resource management to enhance soil productivity'. Could Brazil at the same time decide to encapsulate the Amazon basin, the largest natural phytotron in the world, from any further agricultural or forestry development?

There is circulating widely through the world the idea that many of the problems of tropical deforestation and forest degradation are associated with shifting cultivation, 'slash and burn' agriculture, or whatever name the practice is known by in the different parts of the world. At one time, FAO put out the statement that 10 million hectares of tropical forest are being destroyed every year by shifting cultivation, and the world media continue to remember this figure. Certainly the practice is very widespread. In our studies in the SOS programme, we found the practice in use in Columbia, India, Indonesia, Mexico, Nigeria, Peru, the Philippines, Papua-New Guinea and Zaire – in fact, in every country considered except Jordan.

If we can measure the extent of the problem, perhaps we may be able to find means to manage it. Landsat images of part of Sarawak in the north of the island of Borneo show that even small patches in the forest can be easily distinguished from the forest itself. The area of shifting cultivation and the changes that have taken place during the last 10 years can consequently be measured with some accuracy, and so provide a basis for management decisions. The area under shifting cultivation in Sarawak clearly carries more trees than are left in the area of Borneo (Kalimantan) now being cleared as part of the Indonesian internal migration scheme.

The area destroyed by the devastating forest fires in East Kalimantan are also visible on Landsat images and the extension of clearing along the roads and the rivers are clearly shown. In aerial photographs taken two years after the fire, it can be seen that the ground has already been covered by a 'meadow' of young trees, through which the bare stems of the trees that died stick up like matchsticks.

If we hope to be able to manage the 'problem' of shifting cultivation, it is necessary to discover why the people are still doing it. Why do they go to all the work of cutting down trees every few years instead of practising better husbandry on the plots cleared earlier.

In the SOS programme, we asked the farmers themselves if they knew that the fertility of their lands was declining? Were they aware of erosion? The answers were clear. Almost all of them knew that their lands were declining in productivity, though few of them associated this decline with erosion. Asked what they would do to restore fertility, the answers were unanimous: 'Let the land go back to forest again'.

With the hindsight of experience, we can see that their reasoning was good. Many of the trees are nitrogen fixers, and many of them have deep roots that can act as nutrient pumps, collecting mineral nutrients from the water draining through the profile or at the face of decomposing rock fragments, and returning the nutrient to the surface soil in leaf fall. If there is sufficient land and fertilizers are unavailable or too expensive, reason dictates continuing the practice, with its low external input and minimum use of fossil energy.

Our enquiries, however, showed that all the farmers questioned – except in the Kivu region of Zaire – knew of fertilizers and of the improvement in yield their use could bring. So why continue the practice? The results we obtained in the Cauca Valley of Colombia provided an answer. Careful costing of the labour and materials showed that renting a piece of 'new' land from one of the large landholders, clearing it, and using it for two or three years for growing cassava showed a much better return on the money expended than farmers could obtain by buying fertilizer and applying it to their own farms (see Table 4.1). Yet in the Cauca Valley, the farmer has to pay rent for the privilege of cutting down the trees on another man's property. How much more profitable must it be in Nigeria, Sarawak or the Amazon, where he pays no rent and just cuts down trees belonging to the community, at the same time providing timber which he can use for fuelwood or building purposes.

Table 4.1 Profitability of cassava on newly cleared and previously cultivated plots, Cauca Valley, Colombia, 1982.

	Newly cleared plots	Previously cultivated plots	
Expenditure	Unfertilized US$/ha	Unfertilized US$/ha	Fertilized US$/ha
Clearing land[1]	113	49	49
Ploughing[1]	116	76	76
Planting[2]	91	91	127
Weeding	247	160	191
Harvesting[3]	158	141	147
Fertilizers[4]	–	–	79
Total costs	725	517	669
Harvest value[5]	965	646	811
Profit	240	129	142

Notes: (1) All labour valued at the wage rate for hired labourers (no meal) (US$4.44 per day); (2) Planting includes fertilizer application if applied; (3) Harvesting includes packing and transportation costs; (4) Average fertilizer expenditure including transportation; (5) Cassava valued at US$9.62 per 100 kg.

Certainly the system of shifting cultivation is an age-old practice, not restricted merely to disorganized tribesmen living in cultural isolation, but also by the ancient and well organized Maya civilization. The records show that the Mayas worked to a definite management plan under which, after ceasing cultivation, they would wait for the appearance of certain species and their growth to a certain height before they cut the trees down again. From my own brief experience of the Maya country, I would doubt if there is much of the tropical forest of Yucatan that has not been cut over many times during the 1,000 years of the Maya empire. The same may be true of much of the tropical forest. For example, in Papua-New Guinea, Crapper [7] calculated that if two longboats of Polynesians had landed on its shores about 20,000 years ago and multiplied at the rate found until recently, with the same practice of shifting cultivation 90 per cent of the forests of Papua-New Guinea would have been cut over at least once since the first landing.

Measure and manage is my topic today. With the survey techniques now available, in the development and testing of which ITC has played a notable part, we can measure both the area of the tropical forest and the proportion of that area which at any one time is being cropped by this system of bush fallowing, which has been found by generations of peasant farmers to restore fertility to their soils.

Is the system a cause of erosion? The answer appears to be 'no'. The results Lal obtained at Ibadan [1] show that the rate of soil lost under slash and burn shifting cultivation, accompanied by the use of litter-mulch, is probably less than 1 tonne per hectare per annum, compared to about 30 tonnes per ha with clear felling and broad-based contour banks in the North American style.

If shifting cultivation, which is really a special form of agro-forestry, shows the prospect of being the best means of cultivating much of the higher rainfall lands of the tropics, there seems to be case for looking for better methods of managing the system. Just as the sown legume ley of 18th century British agriculture and the sown and fertilized legume left of 20th century Australian agriculture were improvements to the system of grazing the naturally regenerated pastures that developed in the fallow years (in use since Roman times), it should be possible to discover and develop trees species that could be sown to give a more vigorous regeneration of the tree fallow, to restore fertility and give protection to the soil surface against erosion. Some 20 tree species are now being recommended for this purpose in eastern Nigeria [1].

Since we can now get a good estimate of the problem areas of land deterioration and can measure the extent to which each problem area is increasing, it seems that there must be serious obstacles to the spread of modern soil technologies of using fertilizers and for conserving soil and water. In the SOS programme, we tried to find an answer. We found that chemical fertilizers, discovered only 150 years ago, were widely known if not always used. On the other hand, the construction of contour banks and other conservation measures to control soil erosion were much less commonly practised, even though they were used 1,000 years ago at Bague in the Philippines and 500 to 1,000 years ago by the Incas, the most spectacular examples being at Machu Pichu (Figure 4.2).

The essence of the Save Our Soils project was to enquire into management, and to determine if possible the extent to which social and economic factors were restricting the use of those two tools of modern management – fertilizers and conservation techniques. Perceived wisdom has tended to put the blame for 'backwardness' in the developing world on the small size of the farms, the large size of the farm families, the low level of literacy, and the subdivision of the holding into several plots.

In the SOS programme, we questioned 10,000 small farmers around the world, and we have found no relationship between farm size or the number of parcels into which the holding is divided and the extent of erosion or with the farmers appreciation that

Figure 4.2 Stone terraces at Machu Pichu, built by the Incas more than 400 years ago. The tallest terrace wall measured was 7m high.

their land was declining in fertility.

Family size and literacy also seemed generally to be without effect. In the high catchments of the Santo Domingo river in Venezuela, where the conservationist subsidy had been operating for 20 years, it was possible to get precise evidence. Under the modification of the scheme that has been operating for the last five years, the farmer is entitled to claim payment for each portion he has completed of an agreed scheme, without having to wait until he has completed the whole scheme. Literate farmers had implemented only 23.5 per cent of their schemes, whereas illiterate ones had implemented 37.5 per cent. The relationship between percentage completion of the work in the first two years and family size is shown in Table 4.2.

Table 4.2 Relationship between the size of the family and the extent to which agreed conservation measures have been implemented (Venezuela).

No. children in family	No. of plots	% implementation of the work in first 15 months
0	4	20
1–3	4	25
4–7	4	33
8–11	4	46
11	1	10

A large family is apparently in advantage (or at least up to 11 children), and provided he can see the benefit from a practice, the illiterate farmer will get on with the job just as rapidly as the literate one.

The overriding factor in the successful schemes we encountered in Madya Pradesh (India), Machakos (Kenya) and in the high catchments of the Andes is that if the farmer can see for himself that the techniques being proposed will bring him more money this year, then he will get on with the job. For a subsistence farmer, there is little point in considering the grandchildren. If he cannot feed his family this year, there will be no grandchildren.

Mr Rector, there is no doubt that we can now measure what is happening to the land surface of the world with some precision. We should soon be able to divide the land surface into zones for which different but appropriate management techniques have been worked out. For both of these activities, ITC will play a vital and almost unique role in showing how we should measure and manage our heritage of the soil, the area and potential of which is the ultimate limit to growth. To do so, we need something of the vision and the understanding what was shown by Professor Schermerhorn when he founded ITC.

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5 Reconnaissance scale soil erosion mapping using a simple geographic information system in the humid tropics

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Abstract

This paper reviews the problems posed in the estimation of soil erosion risk in humid tropical environments at the reconnaissance scale.

Two problems are examined – firstly, the scope of erosion processes operating in humid tropical environments, and, secondly the utility of currently available soil loss and sediment yield estimation models in this environment. In addition the crucial need to recognize socio-economic factors in reconnaissance-scale erosion risk assessment is analyzed.

The paper suggests that the best two approaches to the problem lie in mapping land systems or geomorphological units and assuming a common erosion status for each unit or using information systems to interface remotely-sensed, raster- and vector-data relevant to erosion risk assessment.

The use of information systems in this work is illustrated in an example of a simple information system which was used to estimate potential maximum erosion risk using four groups of physical parameters (climatological, pedological and topographical variables, and variables indicating the efficiency of the channel sediment transport process); and current predicted soil loss status by interfacing the potential maximum erosion risk map with various socio-economic parameters indicative of land-use patterns. The accuracy of the maps were evaluated using ground observations and an interaction classification matrix technique.

Much of the discussion, and the example of the use of a simple information system, is based on work in Sierra Leone.

5.1 Introduction

Soil erosion is one of a number of soil degradation hazards that have to be taken into consideration when evaluating land resources. However, as this paper shows, because soil erosion is a dynamic hazard and possesses both physical and socio-economic attributes, soil erosion assessments need frequent updating. Soil erosion risk assessment techniques which account for these frequent updates have been difficult to attain. This paper focusses on one type of soil erosion assessment, reconnaissance level assessment in the humid tropics. Soil erosion risk assessment is important in the humid tropical environment because erosion risks are very high when vegetation is cleared (Walling, 1982) and at the present time vegetation clearance is proceeding rapidly in many parts of the humid tropics in response to competing land uses for agricultural, mining and general infrastructural development.

Reconnaissance-level erosion risk assessment in this environment poses two pertinent scientific and practical problems.

1. Although a number of techniques have been suggested as soil-erosion-rate and soil-loss-prediction tools these mainly focus on the field or slope-segment scale. Yet in many developing countries the requirement is for general assessments to be made over the entire country as the soil resource base is often only poorly known. How applicable then are these small-scale models in this respect, and, can they be modified to cope with predictions over large areas?
2. Compared to temperate and sub-tropical environments, little is known of the relative importance of different soil erosion processes in the humid tropics. Current prediction models focus on processes of sheetwash, and to a lesser extent, splash erosion and rilling; however it will be shown later that a different emphasis on processes needs to be taken in the humid tropics.

These problems therefore need to be tackled in two ways: Firstly, what processes need to be considered when assessing soil erosion risk in the humid tropics? And, secondly, what methods can be employed to assess erosion risk at a reconnaissance scale that are flexible, can be updated, modified and are transferable between regions? These two questions will be considered with reference to work undertaken in Sierra Leone in the West African monsoonal forest zone between 1978 and 1983.

To enable the case study to be understood it needs to be set in a geographical perspective, and the aspects of the physical and socio-economic environment which are relevant to a study of soil erosion in Sierra Leone need to be introduced. Sierra Leone is mainly situated in the monsoonal rain-forest zone of West Africa between 7°N and 10°N; however the far north and north-east of the country are in the wet savanna zone. Little of the climax vegetation of Sierra Leone can now be found due to extensive vegetation clearance since the mid-18th century for timber and, subsequently, export crops (groundnuts, cocoa, coffee and rubber) and subsistence farming (grazing in the savanna zone and a combination of swamp and rain-fed mixed-rice cultivation in the forest zone). Population densities are relatively high (18.0 people km^2) and this high rural population density, combined with a series of colonial and post-colonial government policies since the 1920's which have stressed agricultural development, has meant that the physical environment in Sierra Leone has been subject to strong economic pressures.

Much of Sierra Leone is characterized by Pre-Cambrian metamorphic and granitic rocks of the West African Craton, although there are also Palaeozoic metamorphic and sedimentary rocks, some isolated patches of Tertiary volcanics and, adjacent to the coastline, a belt of Eocene clastic rocks, (FAO, 1979b). The topography can be divided into five major units (Millington, 1984):

1. The coastal zone which consists mainly of a low-lying coastal plain (developed over the Eocene clastics) dissected by mangrove swamps in the north and seasonally-flooded alluvial grasslands behind a complex of beach ridges and mangrove swamps in the south. The only break in the subdued topography of the coastal zone are the well-dissected Freetown Peninsula Mountains which rise to over 2,000 m along the central coastline.
2. Behind the coastal zone lie the interior plains which consist of a series of planation surface interrupted by residual hills and a series of dambo-like swamps, bolis, in the north-central plains.
3. There is an undulating plateau which covers most of the eastern half of the country which is interrupted by granitic mountains rising to over 2,000 m.

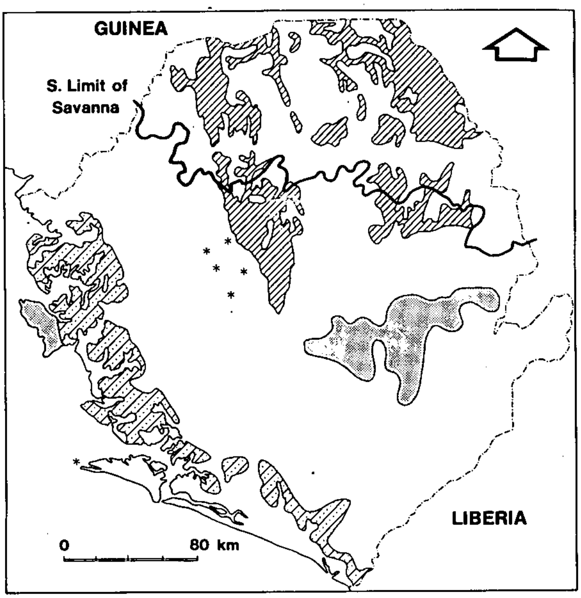
4. The plateau and the interior plains are separated by a well-dissected north-west to south-east trending escarpment zone.
5. The Moa Basin, in south-eastern Sierra Leone, is a well dissected area with topographic characteristics of both the interior plains and plateau.

The soils are broadly divisable into upland and swamp soils. The former are mainly either ferralsols or cambisols or, in the most rugged mountainous areas, lithosols. The swamps soils are mainly gleysols with relatively low fertility contents, except for the thionic fluvisols which are found in the mangrove swamps. Only the upland soils, those not flooded during the wet season, and some of the swamp- and river-terrace soils, which are only flooded in the middle of the wet season, are subject to soil erosion by water. The rainfall is highly seasonal with over 95% of the rain falling between May and November, the most intense rain falls in the first months of the wet season.

5.2 Humid tropical soil erosion processes

The range of soil erosion processes operative in the humid tropics can be illustrated with reference to Sierra Leone, Figure 5.1.

It can be seen from this map that sheetwash, rilling and gullying, the three processes which commonly account for much of the soil erosion in the savanna, semi-arid and subtropical zones, are spatially restricted in Sierra Leone. They occur most frequently



KEY

- Areas of sheetwash in savanna soils
- " in soils developed over the Bullom Series
- Areas of frequent mass movements
- * Occurrences of wind erosion

Figure 5.1 Distribution of surface soil erosion phenomena in Sierra Leone.

in areas with the following pedological characteristics:

1. Low amounts of materials >2 mm in the topsoil (1.8-15.55% by weight).
2. High topsoil sand contents (30-45%).
3. Low to medium topsoil silt contents (15-30%).
4. Low topsoil clay contents (1/315%), and
5. Very variable organic matter contents.

These processes are also more commonly found in the wet savanna zone, the area where mean annual rainfall is 1/32,500 mm; the increased frequency of these surface erosion forms in this area is due to a combination of a greater proportion of erodible soils and low vegetation covers due to the periods of intense rainfall.

Four other types of erosion processes however are found in Sierra Leone and these also need to be considered when assessing erosion risks. Firstly, splash erosion is an important soil erosion process; occurring throughout the country although certain soils are more susceptible than others. It has been recognized as having an important detachment role in many environments (Morgan, 1979) but in the humid tropics it also has been shown to have an important transport role (de Ploey, 1969; Millington, 1985). Secondly the recognition of the importance of subsurface water fluxes in the sediment transfer process in humid environments has increased in recent years (Bryan and Yair, 1982). The high porosity of many humid tropical soils in Sierra Leone combined with the occurrence of subsurface macropores (mainly biopores) means that there is a potential for very fine particulate matter to be lost from the topsoil in matrix flow, macropore flow and percolation, as suffosion, tunnel erosion and eluviation respectively. If soil losses are considered in terms of fertility losses from the topsoil instead of as the amounts of soil lost per unit area then the importance of suffosion and eluviation as mechanisms for soil nutrient losses in solution (Embleton and Thornes 1980) can be clearly seen. Thirdly, it has been shown that mass movements can be important contributors to the sediment budget of rivers in tropical areas (Temple and Rapp, 1972). Thomas (1974) has noted the importance of mass movements in Sierra Leone and has divided them into two types:

1. Rotational slumps in clay-rich regoliths over basic rocks.
2. Mass movements in shallow regoliths over granitic and other crystalline rocks.

Finally, wind erosion is locally important at the end of the dry season when soils experience a seasonal drought in areas with low vegetation cover on sandy coastal soils and silt-rich soils in the bolis that are under mechanical cultivation. Generally however, wind erosion is relatively unimportant in the humid tropics. Of these four processes, splash erosion, subsurface sediment fluxes and mass movements are important in the overall balance of soil erosion in Sierra Leone and need to be considered when assessing soil erosion risks.

Therefore, the water erosion processes important in the humid tropics can be combined into three groups:

a. surface soil erosion processes (splash, sheetwash, rill and gully erosion).
b. subsurface erosion processes (suffosion, eluviation and tunnel erosion), and
c. mass movements.

Research undertaken by the author in the Freetown Peninsula Mountains has clearly illustrated that these three categories of erosion processes can be intricately interlinked in the Sierra Leonean environment. Between 1979 and 1981 erosion plots were established in the Freetown Peninsule Mountains to monitor soil and water fluxes at the soil surface and in the upper 10 cm of very shallow to moderately deep ferralitic cambisols and xanthic ferralsols on slopes ranging from 1° to 17°. Two cropping systems were examined, rain-fed mixed-rice and rain-fed mounded cassava; in addition bare soil and a variety of different ages of forest regrowth and grassland were examined. Two peaks in surface runoff and erosion rates were observed in these experiments, yet only one peak was observed in the subsurface water and sediment fluxes. The first erosion peak, between May and June, was only observed on bare soil and cultivated ground and it was attributed to a combination of high, early wet season rainfall intensities and low vegetation covers. A second peak was observed in the middle of wet season under all vegetation types; this also corresponded to the peak in subsurface runoff and erosion rates, and this was attributed to sheetwash during periods of saturation overland flow. This clearly shows that there is a strong association between surface and subsurface soil erosion processes in this environment which is not untypical of other monsoonal humid tropical areas (Millington, 1985).

The recognition of three groups of interrelated erosion processes in the humid tropics has important implications for erosion risk assessment in this environment. The perception of soil erosion affecting agricultural land by agronomists and agricultural planners usually encompasses rilling and gullying and, to a lesser extent, sheetwash. Splash erosion is rarely considered to be important, yet it has been shown to mobilize large quantities of soils in regions with lower rainfall intensities than the humid tropics (Morgan, 1979). Furthermore subsurface erosion has no visual impact and is therefore rarely considered and mass movements are usually not considered as erosion processes by agronomists although they certainly do have relevance when assessing erosion risks at small scales. Our perceptions of soil erosion processes in the humid tropics therefore need revision; most urgently there is a need to consider other erosion processes besides sheetwash, rilling and gullying. Until we can re-educate ourselves the use of already existing soil loss models will prove inadequate as they will only predict soil losses of spatially restricted, possibly even nonexistent, processes. Moreover, the erosion processes which are presently considered in erosion models, such as splash erosion, sheetwash and rilling, are modelled from parameters encompassing areas of the physical environment. However if subsurface erosion and mass movements are to be considered in soil loss models for the humid tropics then further parameters need to be included when assessing erosion risk, particularly those relating to water movement within the soil, particularly the changes in porosity and permeability down the profile and along the slope, and, for mass movements, the inclusion of soil mechanical indices.

In small-scale erosion risk mapping there is also a need to consider socio-economic factors. Although such factors do not affect the actual physical processes of erosion they do affect land-use practices and therefore have a relevant role in this type of assessment. However, due to their fundamental differences from the physical parameters they are considered separately.

5.3 Socio-economic factors

Reconnaissance level models of soil loss estimation need to consider land use, or the socio-economic factors affecting the land-use decision-making process, in addition to physical factors. This area has been lacking in attempts to model soil losses over large areas so far. Furthermore in considering land-use decision-making processes in humid tropical agricultural systems it is not possible to transfer methodologies from developed countries as the political economy of land use is quite different in these two groups of agricultural systems.

Land use in tropical environments is manifest in the notion of population pressure on the land which has often been described by population density (Boseup, 1965; Gleave and White, 1969), and it is usually assumed that an increase in population density leads to an increase in soil degradation. Gross population density (total population/area) is not a particularly useful variable in this respect in many humid tropical countries as it cannot be equated with pressure on the land. Rural population density (population engaged (or dependent) on farming activities/area) is potentially more useful. However, even in predominantly rural countries such as Sierra Leone gross population density cannot be substituted for rural population density. Unfortunately a functional definition of population density which would alleviate the above problem is beyond calculation given the available data from many censuses in less developed countries. Levi (1976) also cautions that population density, although intuitively appealing, assumes land homogeneity over large areas and of course in many areas this is unlikely to be encountered. He further argues that population confinement, a further assumption of population density indices, is an irrelevant concept in Africa where populations are historically mobile. Both Levi (1976) in Sierra Leone and Helleiner (1966) in Nigeria, as well as demographers such as Ominde and Ejiogu (1972), agree that population density is a poor indicator of population pressure. Levi (1976) suggests that population growth rates, as a reflection of dependency ratios (population/labour), are a far better indicator of land-use pressure.

Bush fallow periods under shifting cultivation can also be considered as indicators of environmental stress due to farming activity. However while providing a theoretically sound methodology, there are practical problems such as the measurement of fallow periods, the fact that they do not account for nonshifting cultivation land uses and the lack of land and soil homogeneity to be weighed against the advantages. Small-scale mapping of bush fallow ages may be achieved once orbiting active microwave sensors are available on satellites but until then our knowledge will remain patchy.

Land cover is perhaps the best integrated variable or set of variables currently available when considering land use at the reconnaissance scale. Land cover has the advantage that it integrates all types of economic activity. Furthermore, if it is subdivided into a series of different land cover types, each with similar vegetation canopy and cover characteristics, then a geomorphologically and ecologically sound method of linking land use (and therefore pressure on the land) to soil erosion processes can be devised.

5.4 Modelling strategies

A number of modelling strategies are currently available for use in soil loss and sediment yield prediction (e.g. USLE (Wischmeier and Smith, 1978); SLEMSA (Elwell, 1980; Elwell and Stocking, 1982) and AOSDA (FAO, 1979a). However when considering already existing models two things need to be taken into consideration; firstly, the scale for which the model was devised, and secondly, its applicability outside the region in which it was devised.

The majority of currently available soil loss estimation models operate on a field scale and therefore have no application at the reconnaissance scale where other factors, particularly socio-economic factors need to be taken into consideration. Both the USLE and SLEMSA fall into this category as do the deterministic, theoretically-based models devised by geomorphologists to estimate erosion rates on small hillslope segments (these are discussed at length by Kirkby, 1980). Yet despite the obvious problems in soil loss estimation over areas larger than the equations were devised for, scale has not always been considered by equation users (Wischmeier, 1976).

The second area of concern involves the regional emphasis of many of the currently available soil loss estimation procedures. This is particularly so of parametric models, which are in essence no more than empirical relationships between measured soil losses and physical (and to a much lesser extent socio-economic) parameters. The problems mainly concern the magnitude of, and the relationships between, the parameters outside the area of initial data collection. A number of studies have shown for instance that the USLE is a poor predictor of soil losses in the tropics. For instance, a study relevant to this paper was conducted by Williams (1980) in Sierra Leone. He found that there was very little association between soil losses predicted by the USLE and actual measurements on 31 farms on a variety of soil types with various slope angles in the Freetown Peninsula. The major problems with the use of the USLE in this environment appeared to be:

1. Rainfall intensities are higher than those occurring in eastern USA.
2. Different methods of soil aggregation that are found in tropical soils – particularly bonding by iron and aluminium (Desphande et al., 1964) and organic acids (Escolar and Lugo-Lopez, 1968; Soong, 1980).
3. Farming occurring on more ecologically and topographically marginal areas, and
4. Cropping and management factors which are radically different.

These observations concur with Stocking's (1979) view that neither empirical nor deterministic modelling approaches provide adequate approaches to the soil loss estimation problem. In the former case because of the in-built regional bias and in the latter because of the large requirements for small-scale data. Although both of these problems have been illustrated by the use of models operating at large scales, the same arguments are applicable at the reconnaissance scale models.

Therefore, in reviewing modelling strategies there are four approaches that can be taken for reconnaissance-level soil loss estimation:

1. The use of either parametric or deterministic soil loss and sediment yield models. However, none presently have been devised in the humid tropics and those currently available do not account for many humid tropical erosion processes or the socio-economic influences on the soil loss process.
2. Stochastic models based on the probability distributions of physical parameters affecting sediment movement in drainage basins have been used to estimate sediment yield in semi-arid areas (Renard, 1977). However, stochastic models need long runs of data to generate the probability distributions and these are unavailable in many areas and in addition they have not, so far, included socio-economic variables.
3. Models which use a land-system or geomorphological map as a base unit and assume a common erosion or soil loss response for similar mapping units. This area

has been underresearched with very few studies being made in the humid tropics, a notable exception being the work of Williams and Morgan (1976).

4. Flexible parametric models specifically devised for reconnaissance-scale assessments particularly those that can include remotely-sensed data in an information system. The FAOSDA (FAO, 1979a) methodology falls into this category but is too rigorous in assuming certain modelling procedures, which may not be universally applicable, at an early stage.

The most promising modelling strategies at the reconnaissance scale appear to be the latter two types.

5.5 The use of a simple geographic information system to assess soil erosion risk in Sierra Leone – a case study

From the view point of national agricultural planning considerations soil erosion hazard mapping should ideally serve three purposes:

1. to assess the current spatial distribution of soil erosion to enable current conservation efforts to be focussed in an efficient manner with a well ordered priority by the identification of erosion 'black spots'.
2. to assess the changes in the spatial distribution of soil erosion if agricultural production is intensified without a national conservation policy.
3. to assess the changes in the spatial distribution of soil erosion if conservation measures are adopted.

The generation of reconnaissance scale soil erosion hazard maps in Sierra Leone using a geographic information system concentrated on the first two types of maps; the generation of the third was not attempted as it was not felt to be appropriate at the reconnaissance scale.

The basis for any soil erosion risk mapping technique or exercise is a conceptual equation; most soil loss prediction models are based on these but even if a model is not being used a conceptual equation is needed as a starting point for ordering data-gathering priorities. For reconnaissance scale mapping the equation can be written as:

$$SL(SY = f(C,S,To,Tp,V,EM)$$

where SL = soil loss (or sediment yield – SY)
C = climate
S = soil
To = topography
Tp = sediment transport system efficiency
V = vegetation
EM = environmental management

Soil loss and sediment yield are in essence the same thing – although soil loss is usually preferred if a slope or field is being examined and sediment yield if it is a larger area. When dealing with soil erosion by water the important climatic factors are rainfall erosivity and water fluxes in the soil or on the soil surface. Soil erodibility indices are usually used as indicators of soil factors. Slope characteristics are usually used as topographic variables although integral variables such as relative relief can be used for small-scale mapping. When considering large areas the efficiency of the river network to transport sediment (soil) from an area is important and in this area geometric parameters which reflect the degree of dissection of the drainage network, e.g. drainage density and texture, are important. Vegetation is rarely unmodified and therefore must be considered in conjunction with environmental management factors. A number of parameters can be used in this common area such as land-use patterns, vegetation cover, national population pressure variables and various aspects of the agricultural systems.

The first of the two maps that was generated was a potential maximum erosion risk map which relates to the second objective of erosion hazard mapping outlined above. There is a need to provide a map to illustrate the patterns of erosion under similar vegetation conditions to ascertain the relative importance of the physical parameters (climate, soils, topography and drainage network efficiency). If any vegetation cover $>0\%$ is taken then the regional ecological differences within a country will be apparent and this would invalidate the objective of examining the contribution of the different physical parameters to erosion hazard; but if a vegetation cover of 0% is assumed (i.e. bare soil) then all soils will have the same cover properties. This then provides a map which allows the relative contribution of different physical parameters to be examined and, in addition, predicts the most serious erosion hazard, maximum soil loss, that could occur due to intensification of land use.

The construction of this map uses the conceptual equation

$$SL\,(SY) = f\,(C, S, To, Tp)$$

In the construction of the potential maximum erosion risk map in Sierra Leone two rainfall erosivity indices were considered as climatic variables. The p^2/P index which was devised for small-scale sediment yield assessments (Fournier, 1962) and the USLE-R factor, as an example of a large scale parametric index calculated by Roose's (1978) modification for West Africa. Systematic soil erodibility index data are rarely available and with the added problems of the choice of erodibility indices for tropical soils many problems frustrate the use of these indices. Three options are available; firstly, the collection of soil erodibility data, whether or not systematic soil analytical data is available; secondly, to estimate soil erodibility indices by a quantitative relationship to systematically collected soil analytical data such as organic matter context or texture; or thirdly, to use another soil property as a proxy variable for soil erodibility. No systematic soil analytical data was available for Sierra Leone and a soil erodibility survey was carried out using a sampling framework based on the FAO soil association map (FAO, 1979b). A mean erodibility index was calculated for each soil association subdivision which related the dispersion ratio of the soil to the gravel and stone content of the topsoil. This was only calculated for those soils not flooded during the wet season (Millington, 1984). Topography was represented by two parameters; firstly, slope angle which has been used at a variety of scales of soil erosion assessment by itself or with systematically-gathered soil information (Dent & Young, 1981); secondly, relative relief was considered as it is a variable which integrates many aspects of the topography of an area and has been used in other small scale assessments of erosion risk. (Stocking, 1972). Drainage density and texture were used as indicator variables to represent the efficiency of the drainage system in transporting sediment from an area; obviously such a variable is only valid at small-scale reconnaissance levels. Drainage density and texture have been used in similar erosion risk assessments in Europe (Iana, 1972; Mikhailov, 1972), the semi-arid zone (Stocking, 1972) and the humid tropics (Morgan, 1979), although in different ways. Iana (1972) and Mikhailov (1972) used drainage density as an index of erosion severity, Stocking (1972) related it to gully erosion and Morgan (1979) regarded drainage density as a better index of runoff in the humid tropical environment of Malaysia and drainage texture as an indicator of gully erosion.

These eight parameters represent a balance between three contraints – those parameters which have been used in other erosion risk studies, those which are important is humid tropical soil erosion processes and the availability of reliable data in Sierra Leone, the latter factor being the biggest constraint in any developing country.

Data which is collected on erosion-promoting parameters is likely to be available in vector form either as a map – in which case it may be found as isoline data, administrative unit data (e.g. census enumeration areas) or land units from land evaluation projects or soil surveys – or as data for various point sources. A common data base facilitates easier analysis of such data sets and to efficiently handle this data a computer-based information system is required. Data handling in this study involved the transformation of existing data sets to a grid square format and the collection of new data within this format as far as possible. There are positive advantages to the adoption of the grid square approach which has been used extensively in other spatial sciences (Haggett, 1965; Robinson and Sale, 1969; Forbes and Robertson, 1967 and Dixon, 1972) and they are an integral part of soil information systems for erosion asessment (Olson, 1981; Webster et al., 1979; Degani et al., 1979; Graze, 1981) and other pedological assessments (Rogoff, 1982; Stocking, 1983; Moore et al., 1981). These advantages are that:

1. Grid square matrices can be generated within computer mapping packages by relatively trivial supplementary programmes.
2. Grid meshes are hierarchical and, unlike irregular polygons, can easily be aggregated.
3. Grid meshes are superimposed on commercial maps and therefore provide a readily available grid framework.
4. Considerable advantages accrue in computerized data storage and retrieval if data relates to a grid structure.
5. Overlay comparisons and statistical testing are easily undertaken.
6. Vector data on a grid format is easily linked with rasterbased satellite pixel data in more advanced information systems.

In the Sierra Leone study 752 100km^2 grid squares were used. These were based on the Universal Transverse Mercator and Clark 1880 Spheroidal projections grids found on all Sierra Leonean 1:50,000 topographic maps, slight distortions were found in the south of the country and the gridsquare size varied by up to 12.09% but as only 2.66% of all grid squares were affected it was felt that this was relatively unimportant in a reconnaissance survey. Similar sized grid squares have been used in other national assessments of various environmental characteristics.

The generation of maps from information systems is usually chosen by combination procedures which assume that a predetermined model is available which relates the data collected to the factor being predicted. For instance Olson (1981) used the USLE to map predicted sediment yields for 1 km grid cells in New England. However given the earlier comments on the applications of models outside the area where they were formulated, and the lack of knowledge of many humid tropical erosion processes it was impossible to use a predetermined model in this study. In one previous study it was found possible to link sediment yield data to parameters for a sample of grid cells (Onstad, 1973) in the form of a multiple regression equation but as no systematic sediment yield data was available in Sierra Leone this could not be done. Therefore a flexible methodology used in regional planning, sieve overlay analysis, was used.

Grid square maps can be easily overlain in sieve overlay analysis as all of the data is available on the same areal units (grid cells). In addition because of the regularity of the areal structure of the data this can be efficiently done within an information system. All the data in this study were transformed to factorial scores before being statistically overlain; a similar technique has been used by Stocking (1974) although it has been critisized by Morgan (1979). The flexibility of the information system used is such that different parameter combinations and weightings of parameters can be analyzed relatively simply and only the best-fit maps accepted. The time savings on non-automated cartographic procedures are selfevident. Computer cartographic packages now provide good quality map products far superior to the line printer products of packages such as SYMAP that were used in similar studies until quite recently. In this work the GINOZONE package was used (a FORTRAN-based library of subroutines that has been available since 1976) on a VAX 1/11 mainframe computer; the methods are described more thoroughly in Browne & Millington (1983).

Table 5.1 An illustration of the calculation of the accuracy overlay maps using an Interaction Matrix Classification Technique. The example is of best-fit Potential Maximum Erosion Risk map in the Sierra Leone case study (Figure 5.3).

	Grid squares with evidence of extensive sheetwash and rilling	Grid squares without evidence of extensive sheetwash and rilling
Grid Squares with high erosion potential	77	131
Grid squares with low erosion potential	76	468

Sum of diagonal units = 545
Total number grid squares = 752
% accuracy of potential maximum erosion risk map $= \frac{545}{752} \times 100 = 72.47\%$

5.6 Potential maximum erosion risk

The potential maximum erosion risk map was generated by overlying the p^2/P erosivity index, slope angle, drainage density and the erodibility index of gravel-free and slightly gravelly upland soils. (Figure 5.2)

This map, and other combinations of the physical parameters, were verified by qualitative observations made over 5 years (1978-1982). To compare the maps to the field

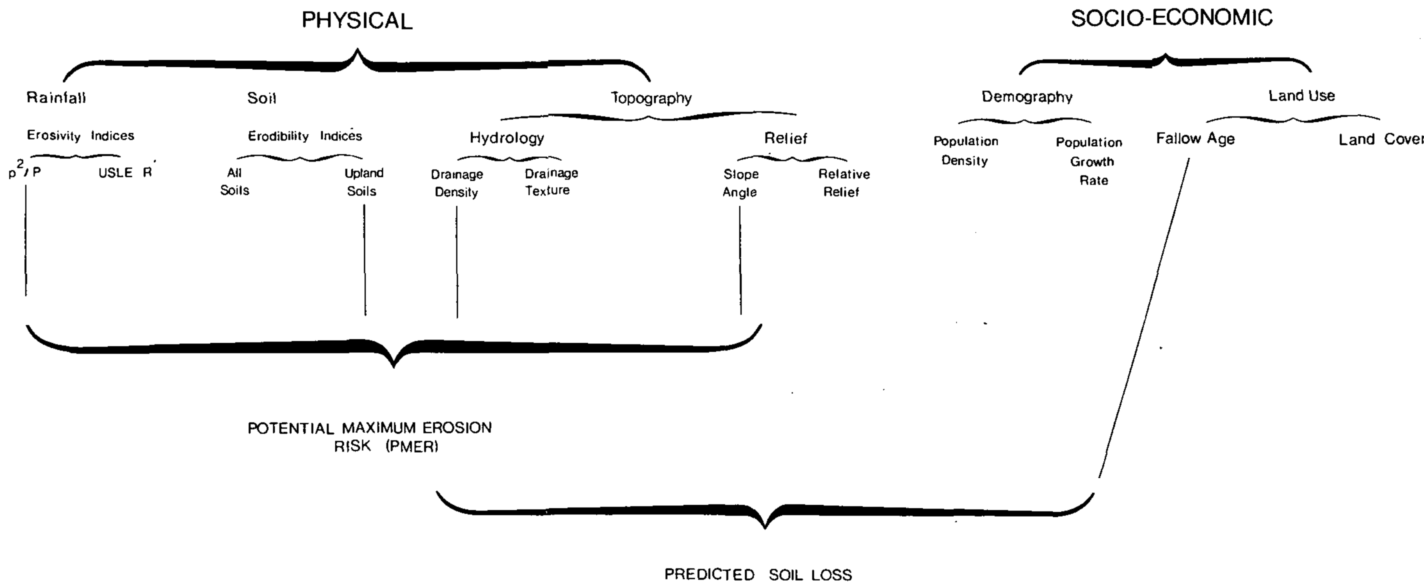


Figure 5.2 Parameter combinations used to construct Potential Maximum Erosion Risk and Predicted Soil Loss maps.

observations a sample of grid squares from each of the five erosion classes were compared to the qualitative observations of different levels of erosion on bare soils and under agricultural and other disturbed conditions using an interaction matrix classification technique; the potential maximum erosion risk map chosen for further investigation had a classification accuracy of 72.47%.

Table 5.2 Accuracy of Potential Soil Loss Maps calculated by interaction matrix classification of overlay maps and test sites.

Non-physical parameter mapped with P.M.E.R. map	No. of grid squares with high erosion potential and evidence of high soil losses	No. of grid squares with low erosion potential and evidence of low soil losses	Accuracy (%)
Bush fallow period	27	11	73
Upland cultivation	24	10	65
Population growth rate	20	12	61
Land in the upland (shifting) agricultural system	18	14	61
Upland grassland cover	18	11	55
Bare rock and soil cover	20	8	53
Population density	16	9	48

The best-fit potential maximum erosion risk map (Figure 5.3) shows two areas with very low potential erosion; firstly, in central and western Turner's Peninsula (in the coastal zone) and, secondly, in the bolilands of the north-central plains.

Areas with slightly higher, but still relatively low, potential erosion are found in the areas along the coast in the Scarcies and Sierra Leone River estuaries, around Sherbro Island and in the other parts of Turner's Penisula. Inland there is an area of relatively low potential erosion flanking the bolilands, an area in the south-central interior plains, southern upper Moa Basin and the central plateau. There are three areas of potentially high erosion:

a. An area adjacent to the northern and central coastal zone which includes the Freetown Peninsula, coastal and interior plains, (northern and western Bonthe, western Kambia and Port Loko, western Moyamba Districts and the Western Area).
b. A very large area including the far northern and central parts of the escarpment zone, the east-central interior plains, western and eastern flanks of the plateau and the northern reaches of the upper Moa Basin, (northern Bo, north and south-east Bombali, northern Koinadugu, central and eastern Kono and central and eastern Tonkolili Districts).
c. An area in the far south consisting of the southern parts of the coastal zone and interior plains (eastern Pujehun District).

These latter three areas should be considered as areas where soil erosion will become a very severe problem if the intensification of agricultural production that is envisaged in Sierra Leone at the present time takes place without recourse to adequate soil conservation policies.

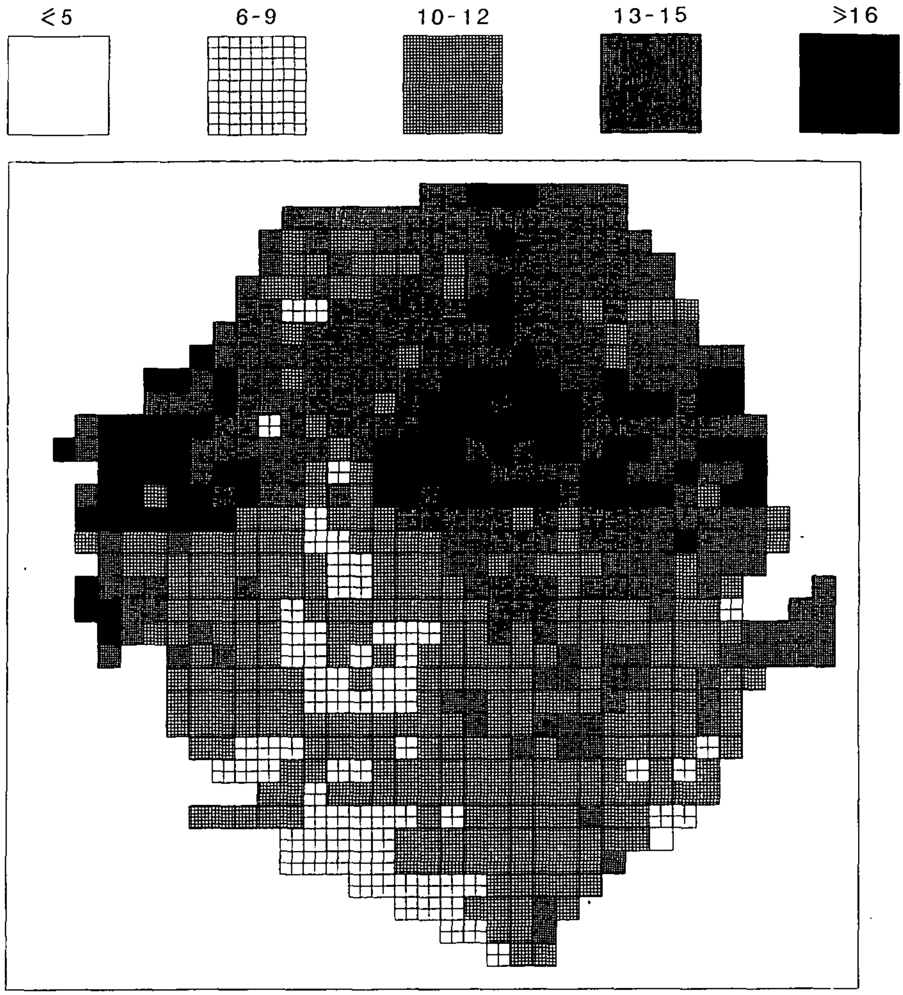


Figure 5.3 Sierra Leone – Potential Maximum Erosion Risk. The factorial scores indicate relative rankings between grid squares and have not been calibrated against field measurements.

5.7 Predicted soil loss

After the identification of future erosion 'black spots' the potential maximum erosion risk map was used as a basis for evaluating present day soil losses. As the potential maximum erosion risk map shows the maximum soil loss, it has to be adjusted to account for present day vegetation cover which decreases the potential maximum soil loss and is a function of socio-economic activity and local and national policy decisions. Three groups of variables representing this latter aspect were evaluated:

1. Land use/land cover maps derived from 1:70,000 false colour infra-red aerial photography flown in 1976.

2. Population pressure variables. Although population density is often used there are strong economic and demographic arguments that in areas like Sierra Leone population growth rates are more important, (Levi, 1976).
3. Bush fallow periods as indicators of pressure on the land and agricultural practices.

The best-fit map – again assessed using field observations and the interaction matrix classification technique – with a classification accuracy of 73% was for the combination of the potential maximum erosion risk map with bush fallow age.

Firstly, there are relatively few areas with low rates of soil loss at the present time and, secondly, the areas with high levels of soil losses are mainly found in the northern half of the country. There are five areas with relatively low soil losses.

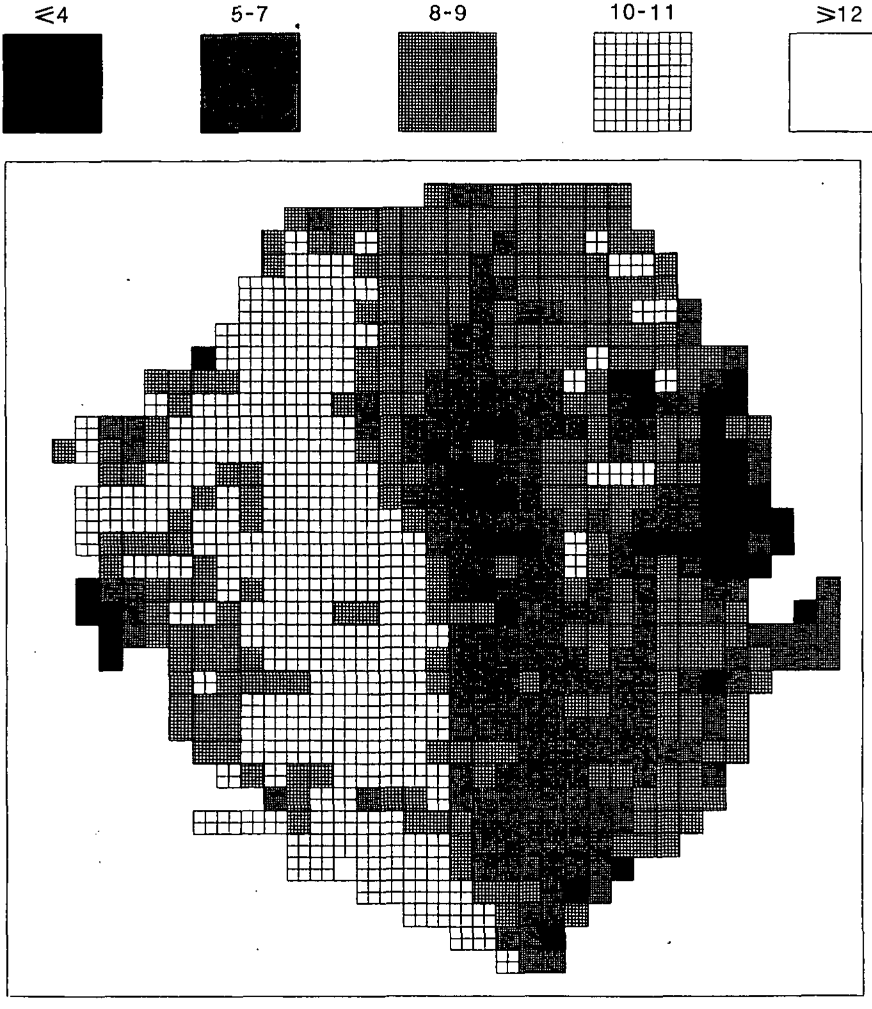


Figure 5.4 Sierra Leone – Predicted Soil Loss. The Factorial scores indicate relative rankings between grid squares and have not been calibrated against field measurements.

1. The coastal zone to the north of Sherbro Island (Bargruwa and Timdel Chiefdoms in Moyanba District).
2. Turner's Penisula and the adjacent baätis (seasonally-flooded estuarine grasslands) along the coastal zone in Bonthe and south-western Pujehun Districts.
3. An area in the south-central interior plains in eastern Moyamba District.
4. The southern parts of the bolilands in the north-central interior plains in central Tonkolili District.
5. An area in Nomo Chiefdom on the Liberian border on the southern flanks of the Moa Basin.

Although most of the areas with higher rates of soil loss form a contiguous area in the northern half of Sierra Leone there are four areas with high rates of soil loss in the south-east of the country.

1. An area in the upper Moa Basin in eastern Kailahun District.
2. An area which includes the northern parts of the Kangari Hills in western Kenema District.
3. The Dodo Hills in north-western Kenema District.
4. The area around Bo in the southern interior plains (Kakua Chiefdom).

Within the northern half of Sierra Leone where soil losses are generally much higher than the south nine areas with very high rates of soil loss can be indentified.

1. The northern Freetown Peninsula.
2. An area in the northern coastal plain and adjacent interior plains in central Kambia and northern Port Loko Districts.
3. An area in the north-western interior plains in eastern Kambia District.
4. An area on the Guinea border in the north-western plateau in Dembelia Sinkunia Chiefdom.
5. The Wara Wara Mountains in the northern plateau in Wara Wara Yagala Chiefdom.
6. A large area extending from the central escarpment zone westwards along the Sula Mountains to the east-central plateau in south-east Bombali, south-west Koinadugu and northern Tonkolili Districts.
7. An area in the central plateau in northern Kono District.
8. The Loma Mountains in Nieni Chiefdom.
9. The northern part of the Tingi Hills in Neya Chiefdom.

These thirteen areas can therefore be considered as erosion 'black spots' at the present time and are in urgent need of remedial soil conservation measures.

5.8 Conclusions

Two general conclusions can be drawn from this study of erosion hazard and risk assessment in Sierra Leone which relate to the two questions posed in the introductory section.

Firstly, there is a need to consider surface and subsurface erosion and mass movements when assessing erosion risk at the small-scale in the humid tropics.

Secondly, two methods for erosion risk mapping appear to be most useful in reconnaissance-scale mapping. Maps of land-systems or geomorphological units which assume a common erosion response for each unit (although these were not discussed at length in this paper) and flexible parametric models utilizing geographic information systems. The latter are preferable at the present time as they enable remotely-sensed data to be interfaced with important environmental and socio-economic data. However, combinations of physiographic, socio-economic and remotely-sensed data need to be urgently investigated using geographic information systems.

5.9 Acknowledgements

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6 Comments on the 'Save Our Soils' (SOS) programme which are of importance for land evaluation.

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On infrastructure

1) The value of land may increase tremendously by the introduction of electricity in some valleys; because the small farmer was able to sprinkler irrigate by electric pumps, the establishment of a quick vegetation cover on very steep slopes (25%) reduced erosion considerably under this type of land use (examples are known for Colombia and Venezuela).
2) The effect of good infrastructure on erosion is also remarkable, consider for example road density in strongly sloping areas; the fact that the people could get materials moved inside and outside the area changed the value of land; however, locally constructed roads may cause erosion; in NSW (New South Wales) 40% of the gully erosion in the past was caused by poor road construction.

On extension service

1) Striking was also the use of the extension officer which varied enormously. In some countries (i.e. the Philippines) there seemed to be an adequate extension service from the top down, but when talking to the farmer all 100 of them said they never saw an extension officer; another factor was the persons mobility; he was often given transport suited for town conditions but completely unsuitable in rough terrain; on top of that it appeared that in 9 out of 12 months no petrol was available.

On terminology

1) This concerns some of the definitions used during the presentation of the last papers; in erosion experiments done some 15 years ago it was found almost impossible to produce sheet erosion; we did get rill erosion at slope (0.5%); a rill will develop when one has any small irregularity at the surface; the effect of many rills may look like sheet erosion; the latter only occurs on a 'cemented' surface; in other areas no rill erosion will take place but entirely splash erosion; this was the case in the forested, sandy area in North Central Queensland, where it was quite serious.

On land evaluation

Looking back at the SOS work, it is evident that land evaluation depends so much on the crop which is being put onto it; one needs to take into account the soil physical, -mechanical, and -biological parameters of an area; what we are losing when we lose topsoil is also reflected in the reduction of the moisture storage capacity; so it is a question of how much soil is gone and what does it cost to put it back again or at least stop further erosion. The soil conservation plan in Australia was finalized five years ago and plans are drawn up combat erosion based on second analysis.

Discussion

van Mourik: Does the introduction of roads in already densily populated areas not lead to more erosion?
Hallsworth: Good roads do not increase erosion but bad roads do; the road frequency is also important.

Mitchell: When constructing roads, the road engineer requires a good understanding of erosion Thus culverts, bridges and drains should be constructed according to specifications based on erosion hazards surveys.
Flach: The sociological aspects are important when dealing with the issue of combating erosion for developed and also for developing countries; the attitude of the farmer towards erosion was questioned in the United States; one question put to the farmer was how severe the erosion problem was and what they thought about the problem of the nation; yes, they saw it as a severe problem; and what about their own state; yes, they thought it was pretty bad; in their own community it was not too bad and there was no erosion problem at their own farm; the utility of the extension offices was also questioned; it appeared that the source of information about erosion came in the 1st place from their neighbours. 2nd place from trade journals. 3rd place from fertility and machinery dealers. 4th place from soil conservation offices. 5th place from extension officers.
Hallsworth: Yes, this may be true; but the situation in the States is different because you are dealing with an almost complete literate population; indeed one farmer was told he lost 1 mm of soil a year, but he was also told that he laid 25 feet of it, so he thought 'that will see me out; however, indeed a good extension officer with frequent visits is very effective; for example in India visits were made at least once every two months; in other countries the system of obtaining loans for soil conservation works was prohibiting direct action and often people would not loan from the banks or from a cooperative but from friends and/or family or even a money lender, because in these cases no letters nor elaborate forms had to be filled in and the money was more readily available (this was the case in some parts of Nigeria).

McCormack: In addition to comments by Dr. Flach it is pointed out that often SCS officers would point out that loss of productivity may only occur after 10 generations, thereby suggesting that the present loss of soil and therefore productivity is not fully appreciated by the farmer.

7 Aspects of mapping units in the rain erosion hazard catchment survey

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Summary

Chapter 1

The rain erosion hazard survey of catchments on scales of 1:15,000 – 1:50,000 aims to produce maps showing the expected rate of soil loss under the present land use and management. The erosion hazard may be shown in qualitative and relative classes, but preferably in classes of a quantitative character.

The potential erosion can be shown on the same map, for conditions of bare land and ploughing down the slope. On the basis of this potential erosion, maps can be made showing the actual expected erosion under alternative types of land utilization, which are defined combinations of land use and management.

The development of erosion hazard with time shows the influence of the natural stages in the erosion processes, as well as the human influence of agricultural land use and conservation practices.

Chapter 2

The survey of erosion hazard has to deal with cases of both uniform and non-uniform erosion occurrences.

Chapter 3

When erosion hazards can be mapped with units of a rather uniform character, a mapping procedure is described using the common erosion factors of climate, relief, soil profile, present active erosion, land use and management. In this mapping procedure, the following points are considered:

- creation of the main mapping units (landtypes).
- climate.

- soil mapping units.
- relief susceptibility to erosion (slope steepness, erosion slope length, position and exposition). In the discussion of the effect of slope steepness, results of recent research at ITC on boundaries of steepness classes for steep relief have been included.
- present active erosion. A review of erosion features and the relationship of erosion features and erosion hazard is given. Attention is asked for zones of rill erosion.
- soil erodibility, comprising two groups of influences: the 'overland flow production' by the soil profile and its landscape position, and the 'availability of material for erosion'.
- the classes of potential erosion and actual erosion hazard. They are mostly relative and qualititive but they may sometimes be expressed in soil loss as ton/ha/year on the long term. The amounts of soil loss of the lower two classes fall in the range of soil loss tolerances, the medium class will be the range of soil losses that are too high but usually have to be accepted, and the two highest classes have the soil losses that are destructive to the land with serious effect on the yields, within a period of one farmer's working life or an even shorter period.

  The soil loss classes have a level that differs by a factor 2 from the next higher class. In this way it is hoped that the classes will facilitate incorporating the influences of other erosion hazard factors of mapping units if they also could be expressed in classes differing by a factor 2.
- land use. This is most often the dominant factor, interfering with splash.
- field pattern and colluvial steps.
- conservation practices.
- legend and mapping units. At this stage, a check is made to see if each legend class describes well all the mapping units belonging to it.

Chapter 4

The causes for a non-uniform occurrence of erosion are investigated. An overview is made of the effects of these causes in three categories: a) effects that can be generalized for a mapping unit.
The effects that cannot be generalized for a mapping unit are split into two:
b) effects that generally cannot be mapped on scales of approximately 1:10,000 – 1:50,000
c) effects that can be mapped on scales of approximately 1:10,000 – 1:50,000

Some effects can come under more than one of these categories depending on their size and frequency of occurrence. The following effects are considered:
- Bad spots.

  By cattle trails, footpaths, roadside furrows and ditches, camping sites and recreation sites, overtopping of field boundaries or contour furrows or conservation terraces, drip zones and concentrated stemflow in forest land, grazing sites in grassland, urban drainage outlets and drainage from village ground and farm compound.
- Natural inhomogeneity of the erosion processes.

  By variable flow patterns, local moisture concentrations (from splash concentration, shallow subsurface flow and topsoil saturation overland flow) in hollows and con-

cave or flat land.
- Variation in topsoil.
- Erosion conditions on a hillslope scale.
  By great variation in parent material (thin dipping layers), great variation of surface micro-relief, an irregular soil profile horizonation
- Erosion conditions on a hillform scale.
  By thick dipping strata, orographic rainfall, period since reclamation

Chapter 5

The use of the erosion toposequence is discussed. The erosion toposequence is a series of erosion features and corresponding deposition features, recognized by type and intensity, occurring on a hill from the summit along the slopes down to the drainage-way, when this sequence occurs repeatedly in a certain area along hillslopes of similar shape and substratum influence. The erosion toposequence indicates the natural tendency of the erosion in the landscape. It can be of help in mapping erosion hazard. Partial erosion toposequences may occur, depending on erosion conditions. The absence of the sequences also gives information about the erosion hazard when the causes for the absence are understood:
low rainfall and permeable soils, very gentle slopes, an effective protective plant cover, a highly erosion resistant soil, irregular erosion conditions.

Chapter 6

The erosion toposequence also gives information about the occurrence and the character of the overland flow in the area.

Chapter 7

Expected soil loss as an expression of erosion hazard is important, but it does not always indicate the effect of erosion on the land suitability and the yields of crops. Soils react very differently to a same amount of soil loss.
Therefore the sensitivity of the soil to productivity losses by erosion should be added to soil loss to make an index for the need of conservation. Though an erosion hazard above the soil loss tolerance value always indicates a need for conservation, a combination of erosion hazard and the sensitivity of the soil to productivity decline from erosion forms a better criterion of the need of conservation.

7.1 Introduction

In the rain erosion hazard survey for on-site erosion, the effect of the land use and cultivation system on erosion hazard is shown on maps. These maps preferably also show the potential erosion which exists in the absence of vegetative cover and protec-

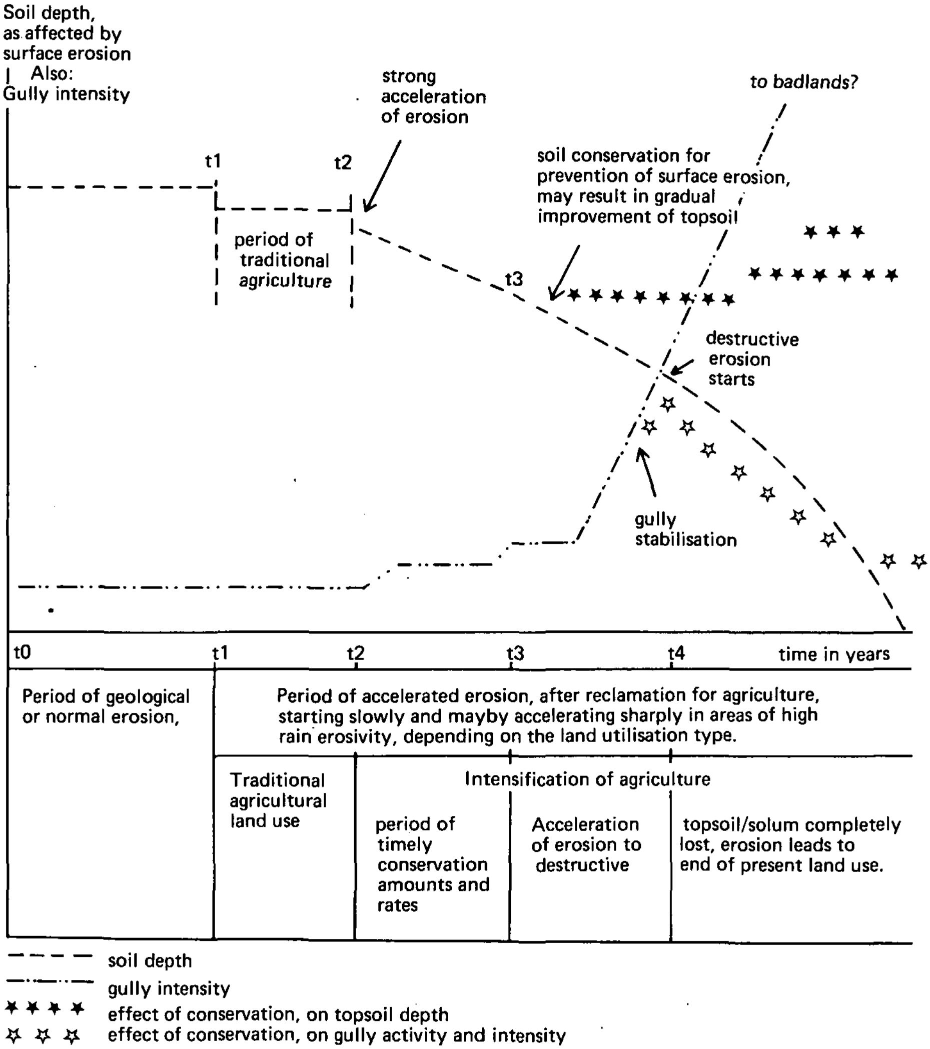


Figure 7.1 The development of erosion with time.

tive practices. Different land utilization types, which are combinations of land use, cultivation system and management, lead to different actual hazards on land with a certain potential erosion.

The maps can also indicate the erosion hazard expected after improvements, for instance those which are feasible within the present land utilization type. Using the same basic data, erosion hazard maps can be made showing the expected erosion for various alternative types of land utilization.

It is clear that the erosion hazard map is a valuable basic document for land-use planning and conservation in sloping areas. 2

The expected erosion or erosion hazard can be expressed in relative, qualitative classes when not many erosion data are available. Preferably one would use absolute classes, so that areas of different conditions in different parts of a country can be compared. The best are quantitative classes which however need a good evaluation system, such as the USLE for the USA (USDA 1978) and the SLEMSA for southern Africa (Ellwell, 1981).

The rate of erosion shows changes which are caused by the interference of man by bad practices or by protective measures. This is illustrated in Figure 7.1

7.2 The approach for uniform conditions

The mapping units which are shown on the rain-erosion hazard map are created on the basis of land characteristics that determine the degree of erosion in the near future. On intermediate scales of 1:20,000 to 1:50,000, these maps often cover a subcatchment area and are used for general planning. For the individual farms, farm plans may be drawn up later on larger scales. The (sub)catchment study itself may result from smaller scale erosion danger inventory maps, made for large areas.

In many situations, the topsoil erosion has a character that is sufficiently uniform to allow generalization. This is especially true for agricultural land under annuals or perennials, when a somewhat greater uniformity of the soil surface and erosion is often to be expected under uniform land management.

Land, plant (crop) and management characteristics that are used in the erosion hazard survey are discussed in the following Chapter 3. They imply a largely uniform character of the occurrence of the erosion. The case of non-uniform erosion occurrence when other factors than discussed here become of dominant importance, is dealt with in Chapter 4.

7.3 Land, plant and management characteristics used for the rain-erosion hazard mapping, in the context of the mapping procedure

Land, plant and management characteristics that influence rain erosion hazard are grouped in categories, the erosion factors. These factors are listed in Table 7.1, schematically, omitting some important interactions between factors:

Table 7.1 Erosion hazard factors in a mapping unit.

1) Climate	)		)	
2) Relief	)	→ POTENTIAL EROSION	)	
3) Soil profile	)	(bare fallow,	)	
4) Present erosion	)	tillage // slope)	)	ACTUAL
			)	→ EROSION
5) Plant cover	)		)	HAZARD
6) Conservation practices	)	LAND UTILIZATION TYPE	)	

The hazard factors, and their characteristics, are surveyed by airphoto-interpretation and fieldwork. For erosion hazard surveys on intermediate scales and of a semi-detailed or reconnaissance character, the survey procedure is to a large extent that of soil survey.

The soil survey is a practical basis for the erosion hazard survey because soil mapping, which is mostly done on a physiographic basis, takes into account the relief, soil profile, effects of vegetation and land use and effects of protective practices if they have altered the soil. Therefore, a soil survey is a good start for an erosion hazard survey. Some hazard aspects need more information, some soil aspects can be generalized and shortened. For instance, more data are needed about slope steepness and overland flow occurrence, about surface gravel, plant cover during the year, soil erodibility, etc. Less information may suffice about soil genesis and soil classification.
The following steps are part of the rain erosion hazard survey.

7.3.1 Main mapping classes

Main mapping classes, called 'landtypes', are first recognized. They are based on:
a) relief,
b) parent material
c) vegetation/land use.

7.3.2 Climate

A general type of rain characteristics and its corresponding level of rain-erosivity can be assumed for a limited survey area in most cases. If extensive parts of the area differ significantly in elevation, one has to consider if orographic rainfall is causing important differences in erosivity.

7.3.3 Soil mapping units

Mapping units are based on soil survey. The soil mapping considers elements of airphoto-interpretation (Bennema & Gelens, 1969) as follows:
a) relief and slope,
b) variations within a parent material,
c) drainage pattern
d) drainage conditions,
e) natural vegetation and land use,
f) parcelling, etc.

The physiographic soil mapping units that are so created have a great value for mapping the land units used in land-use planning and conservation.
The units have a certain character of land characteristics, and most often also a certain character with respect to plant cover and management, the two components of the land utilization type. In some cases soil mapping units have to be subdivided to arrive at units more exclusively belonging to one land utilization type.

7.3.4 Relief susceptibility to erosion

The influence of the relief on erosion could be called perhaps the 'relief susceptibility to erosion', to have an appropriate term that can be used just as terms like rain-erosivity, soil erodibility, etc.

For erosion hazard mapping, the soil mapping units are to be described in more details regarding the following relief subfactors. Only in rare cases are the original soil mapping units subdivided on the basis of these relief subfactors:

7.3.4.1 Steepness

Steepness classes are strongly related to those of soil survey:

Nearly level	0– 2%
Gently undulating	2– 4%
Steeply undulating	4– 6%
Gently rolling	6–10%
Steeply rolling	10–16%
Hilly	16–25%
Steep	25– ?%

These classes have narrow ranges. They are not meant to be a basis for the creation of mapping units, but they are used only to describe the mapping units that have been created for the soil mapping. The classes have been designed to indicate the same relative influence on the erosion hazard for surface rain-erosion, combining the inter-rill erosion and rill erosion. In each class increment the hazard will increase approximately by a factor 2.

To repeat, the steepness classes of erosion hazard are to be used to describe the physiographic soil mapping units. They are not meant to be used to create mapping units based on slope steepness. This would lead invariably to a confusing mass of units. Only in rare cases is a large physiographic soil mapping unit better subdivided for erosion hazard using slope steepness, for instance by recognizing within the undulating range a steeply undulating and a gently undulating part, or a gently rolling and a steeply rolling part within the range of rolling relief. Above 25% classes of relief susceptibility of surface erosion are uncertain. A question mark has therefore been put in place of the boundary value of slope percentage.

Recent ITC investigations have provided a basis for steepness classes in steep (8) relief (ITC Field Report of the Erosion Group 1983, and 1984, and MSc study of Mr.Mulegeta 1985 of which the report is in preparation). Provisional conclusions about the steepness classes are:

25– 40% – the hazard increases by a factor 2

40– 60% – the hazard increases by a factor of root 2.

60–120% – the hazard is roughly the same as in the previous class.

In these steepness classes for steep relief, consideration is given to the reduced rainfall amount per surface area, the decreasing effectiveness of inter-rillerosion (Bryan, 1979), and the relatively smaller amount of runon occurring on the steep slopes in the cases investigated.

7.3.4.2 Erosion slope length

The erosion slope length is the length of uninterrupted eroding overland flow. It starts from the beginning of overland flow and continues down to where flow concentrates in well defined channels, or to where deposition occurs.

The first approximation of the erosion slope length is provided by the length of hillslope.

The second approximation is by slope form: the concave slope form, often being depositional, is excluded from the erosion slope length. For gully erosion slope form also has an important influence as hollows and other subcatchment topography give a higher gully hazard, just as concave slopes often do by their moisture accumulation (Zaslavsky, 1981a).

The final determination of erosion slope length requires field observations, which will determine the real length of eroding overland flow. This may lead to recognizing overland flow zones of very small extent, covering 1-10% of a subcatchment area, with very short slope length values. If these areas have an easy delivery to the drainage system, they are similar to the hydrologists 'partial areas', which produce the peak flows in the discharge regime of a stream by topsoil saturation overland flow from a very small part of the catchment.

The case of slope steepness classes, the slope length classes are to be used to describe the mapping units created on the basis of physiography in the soil survey. Only in rare cases will the length classes be used for subdivision of soil mapping units for soil erosion hazard mapping. The classes have been created in combination with the steepness classes. They describe combined ranges of relief steepness and erosion slope length that differ in rain-erosion hazard by a factor of 2. They are used to describe the range of conditions in mapping units, and not observation sites (for which the generalization would lead to lowered accuracy).

Classes for the erosion slope length are:

Very Short	12– 30 meter
Short	30– 70 meter
Medium	60–150 meter
Long	150–300 meter
Very Long	300+ meter

7.3.4.3 Position (extra inflow, runon)

The position of the mapping unit relative to the surrounding area indicates whether the unit is lying below other units from which it may receive runon. If runon occurs, it leads to a modification of erosion slope length by adding the length of runon entering the mapping unit from outside to the erosion slope length within the unit. In case of gully erosion the catchment size of the gully head is of importance for the hazard.

7.3.4.4 Exposition of hillslopes

In large ridges, of general East-West direction, exposition may cause differences in erosion conditions that are mappable. 2

7.3.5 Present active erosion

The intensity of present erosion is often used as a first indication of the erosion hazard. It can be judged, to some extent, from the present active erosion features.

Erosion features that are often used in the description of the present erosion are those of surface erosion, gully erosion, tunnel erosion. Mass movement, riverbank erosion, coastal erosion are determined largely by other factors than those used for rainwater erosion. The common features of rainwater erosion can be grouped in a diagram in a general way, according to slope steepness and the amount of overland flow. (Figure 7.2)

The processes depend on rainfall, material, position, slope form, land use and time. This may sometimes result in regular sequences of features along hillslopes. Deposition is mainly determined by slope shape, basal plant cover, surface depression storage, and overland flow infiltration. Deposition is often very local but can be very damaging, as it is receiving material from large areas, even when under low acceptable erosion rates.

Slope	Erosion Features					Deposition Features
Steep				badland		
	○ rills	+ shallow gullies	+ deep gullies	+ very deep gullies	+ ravins	fans
Very Gentle	× directional wash	○ rills	○ braids	○ wide braids		collovium, slope wash deposits
Flat	• reticular wash	× directional wash	○ wide braids	sheetflood zones		sheet deposits
	LOW	MEDIUM	HIGH	VERY HIGH		DECREASING
	OVERLAND FLOW VOLUME					

Legend: • = dominant spash and flow in discontinuous microdepressions
× = dominantly flow in discontinuous microchannels
• and •• and × belong to interrill erosion
○ = dominantly flow in continuous but temporary channels
\+ = dominantly flow in permanent channels
Λ = depositon by gravity and wash.

ITC.EB. 1970-1984. Adapted from: Richter 1965/Carson & Kirkby 1972/Bergsma 1974.

Figure 7.2 Features of rainwater erosion (schematic diagram).

A comparison between the erosive capacity splash erosion, interrill erosion and rill erosion gives a ratio of 1: 50: 2,000 (Morgan, 1979). It is therefore of great importance for erosion hazard mapping to separate zones of rill erosion.

Gully depth classes may have relevance for the hazard of future erosion, and for the damage that the gully does to the land. Shallow gullies would interfere with land tillage, deep gullies would in addition interfere with the communications on the farm, and very deep gullies would in addition affect the water regime of large areas of surrounding land, as well as have a high hazard of branching and sideways extension.

Present erosion has to be distinguished from past effect. Evidence provided by the soil profile and the plant cover is more related to the accumulated effects of past erosion, and does not have to be a good guide on future erosion. This is illustrated in Table 7.2.

Table 7.2 Erosion features and erosion hazard.

Stage of development of the erosion process	initial	young	mature	old
Erosion hazard	moderate	high	moderate	low
Active erosion features	few	many	common	none

The use of the visible rain-erosion in the field as an indication for the rain-erosion hazard has to be done with caution. One has to be aware of the development stage of the erosion; otherwise one may mistake strong evidence of past erosion as an indication of strong hazard. This is correct for situations where erosion is in full progress, but it is wrong where erosion is in a final stage, reaching a new natural equilibrium. For example, where surface gravel has accumulated on the land surface as a result of rain-erosion, it will slow down the subsequent erosion to low rates. Another example is where gully erosion has reached, in most of its branches, the stage of maturing or stabilization.

Present erosion may also be misleading as an indication for the erosion hazard, when erosion is young and is still actively developing. This can happen especially when a change in land use has not yet had its full effect by increasing present erosion, while the erosion hazard is already strongly increased (see schematic diagram). In certain conditions the activity of headward growth of a gully head is indicated by the height of the gully headface (Stocking, 1980), which may be increasing still, or be decreasing.

7.3.6 Soil erodibility

Soil erodibility is determined mainly by overland flow generation and the availability of erodible material (a recent reference: Roels, 1984 b). The most important subfactors of soil erodibility are listed in Table 7.3.
The availability of material for erosion should include the material that is readily available even without splash, such as fine sands.

The soil surface gravel has a strong influence on erosion by preventing splash.

Depending on soil sealing, the infiltration under rainsplash may be very much lower (ten times or more) than infiltration in protected condition. For piping erosion a dis-

Table 7.3 Aspects of soil erodibility.

Soil Erodibility	
Erodible material	Overland flow production
– Soil Surface Structure (grade, size, type) – Structural stability or detachability (of surface soil) – Surface gravel	– Depression storage – Surface sealing – Infiltration (under rain) – Permeability – Profile storage (macroporosity and depth of permeable topsoil) – Drainage (steepness, slope form, runon and seepage)

persion index may be useful (Stocking, 1978).

As there are so many aspects that determine soil erodibility, it seems best to test several aspects of the soil and conclude on its erodibility class by reviewing the spectrum of the test results. A similar conclusion is reached by Lal (1981) in a review of hazard factors for rain erosion in tropical Africa.

7.3.7 Potential erosion

There are 5 classes of potential erosion: Very High/High/Moderate/Low/ Very Low. The term 'moderate' is used for hazard as the intensity of the process, the term 'medium' is used to indicate the amount of soil that is going to be lost. When a quantitative prediction of erosion hazard is allowed, the following classes are used:

Very Low	=	0– 5	t/ha/year
Low	=	5–12	t/ha/year
Medium	=	12–25	t/ha/year
High	=	25–60	t/ha/year
Very High	=	60+	t/ha/year

The lowest two classes are within the range of soil loss tolerance values. The moderate class is aimed to cover the hazard in situations where erosion is somewhat high but needs to be accepted, on most farms, for the time being. The class of High erosion is unacceptable for any land use aiming at sustained productivity. The erosion in the class Very High is destructive for the land in a short period, for instance less than 10 years.

For the off-site effects, these qualifications may be very different. Erosion is often a non-point sediment source that may proceed at non-damaging rates on the land, but may be very damaging by concentration of the sediment in very restricted accumulation sites. Flooding may result from small increases in overland flow over large areas. The off-site effects may be strongly damaging while the upslope erosion rates can still be acceptable.

The erosion hazard increases with steepness, roughly by a factor 2 for each steepness class. The classes have been designed in this way (Bergsma, 1983). (12) When each erosion factor could be expressed in classes differing by a factor of 2, the effects of the erosion hazard factors which are so different in character, could be put together and expressed in the hazard rating. This has been tried (Bergsma, 1983 and Bergsma, 1985,in preparation). The system would be useful to deal with the range of conditions in mapping units, but not for individual sites or small fields.

7.3.8 Land use

Land use is the most important erosion factor because its effect is dominant over all other factors. A steep slope under a good cover will show little erosion, even in a climate with very aggressive rainfall, or on an erodible soil. This is because the cover prevents the process of splash, which most often produces the erodible material. Plant cover also slows down overland flow which is of special importance for gully hazard. Plant cover favours soil life and by its rooting may increase the infiltration. On well protected steep slopes, not rain-erosion but mass movements often form the highest hazard.

The land-use effect is largely a matter of plant cover. One can distinguish three partial effects: (1) the canopy effect, which depends on the crown density, height above ground, and degree of closure, (2) the so-called 'mulch effect' of residue and low plants, which is the most important because it describes the effective interception of splash and slows down the overland flow, and (3) the residual effect which lingers for some years after the causal vegetation has gone. It is the influence of remaining organic matter, soil structure, etc. The residual effect explains part of the differences in erosion under various crop rotations (USDA, 1978).

Plant cover of the soil surface has to be well recorded in the field. Classes in the field have for instance a 10% interval. For the total annual effect of plant cover, growth stages (for annuals and for perennials with varying foliage) are considered and combined with the rainfall erosivity distribution over the year.

For the mapping units, the dominant land use is considered (covering 100-70% of the unit), and a subdominant land use may be indicated (covering 30-40% of the mapping unit). In some cases subdivisions of the soil mapping units are made to separate strongly differing types of land use, arriving at mapping units that are more exclusively belonging to one land utilization type.

7.3.9 Field pattern and colluvial steps

Modification of erosion slope length is sometimes caused by field boundaries that interrupt frequently the overland flow in certain mapping units. This is, for instance, the case in some traditional field patterns where boundaries follow roughly the contour lines. At these boundaries, colluvial terraces may develop, indicating that the erosion and accumulation processes have been active for a long time. Colluvial terraces are evidence of a moderate to high rate of erosion in the past and possibly continuing to the present. One may consider whether this can be attributed to the rainfall, the soil, the management system, or a combination of these or other factors.

Modification of the erosion slope length can also be caused by contour roads, contour ditches, farm compounds, stratigraphic contour outcrops, etc.

If these interruptions of the overland flow occur regularly, they may be taken into account for the erosion hazard of a mapping unit.

7.3.10 Conservation practices

Conservation practices consist of two groups: (1) the vegetative practices, difficult to detect on AP, and included in the erosion factor of land use, and (2) the mechanical practices, which are often detectable on AP, especially when they are part of a contour farming system:
= Contour tillage
= Contour stripcropping
= Contour terracing
For mechanical contour farming practices such as contour-tillage, contour-strip-cropping, and contour-terraces, the potential erosion hazard is usually even greater than the unrestrained erosion in the corresponding zone of the erosion toposequence, because these practices, when they fail, cause a strong unnatural concentration of overland flow.

7.3.11 Legend and mapping units

At this point in the mapping procedure one has to check if mapping units are correctly described by legend classes. If mapping units of one legend class differ too much in erosion hazard conditions, the mapping units of that mapping class are given a serial number and they are listed. In the list, the individual character of each mapping unit is described, together with the conclusion on its erosion hazard. Thus the hazard is described for individual mapping units and the mapping class is not generalized as a whole.

7.3.12 Actual erosion hazard

There are five classes, the same as in potential erosion. The potential erosion is reduced, usually strongly, by the influence of plant cover and the management/cultivation system. For each land use and management combination the actual erosion hazard can be determined, based on a land unit with a certain potential erosion.

7.4 Causes for non-uniformity

In many other situations, there is not such a uniformity of soil erosion as was presupposed in the previous Chapter 3. Erosion may be non-uniform for instance because of local strong effects by animals or human influence on land cover, or because of a great variation in general natural erosion conditions, for instance parent material. A certain amount of non-uniform rain-erosion is present in almost all situations. This non-uniform, irregular occurrence of erosion cannot easily be described in a general way as is done for more uniform mapping units.

The non-uniform influence of gull erosion on the land is well known. Another cause of non-uniformity of rain-erosion is in the processes of surface erosion. Interrill erosion, prerill erosion and rill erosion occur in a partly variable flow pattern. Within one field, even apart from the influence of slope form or the erosion – deposition contrast, differences in erosion intensity exist because of different importance of erosion processes from spot to spot (meter to meter). This non-uniformity within a field on one type of slope is described and studied by Roels (1984). It has implications for measuring erosion in the field, and for the understanding of the erosion processes and their importance under certain rainshowers. Certain processes start together with the rain, other processes occur only after a certain time and a certain volume of overland flow has been reached. A research perspective on erosion and productivity (National Committee, 1981) also mentions the non-uniform character of soil loss caused by the character of the erosion processes within farm fields of otherwise uniform conditions.

Apart from the variable flow pattern, the non-uniformity in the erosion processes of surface erosion are also attributed to very local moisture concentrations which are caused by a local horizontal flow component (Zaslavski, 1981 a). This leads to local overland flow at low rates of rainfall and to seepage forces, both contributing to erosion. The very local areas of (14) saturation at low rainfall are explained from three sources:

- the effect of surface roughness, concave slope parts and concave slopes on splash distribution (furrows, microrelief and slope form)
- the effect of flow immediately below the soil surface
- the flow patterns in a layered soil.

These effects do not conform to the concept of Horton overland flow, nor with the concept of the Topsoil saturation overland flow. The effects explain the occurrence of erosion at rain intensities well below the general infiltration rates, and before a pseudo-water-table has built up preventing infiltration of further rain. It is concluded that the overland flow depends strongly on the antecedent moisture (moisture content of the soil before the rainstorm).

Another cause of non-uniformity of erosion conditions may be related to the variation in topsoil. This is also true for tropical areas, where pronounced soil formation is sometimes considered to homogenize soil differences caused by variation in parent material, slope and other factors.

Erosion may occur in very local spots of very high intensity, sometimes calledthe BAD SPOTS of the land unit. Local strong erosion may occur in arable land, grazing land, forest land, and peri-urban land, because of the effect of:

- cattle trails, footpaths (in grassland)
- roadside furrows and ditches
- camping sites, recreation sites
- overtopping of field boundary barriers by overland flow
- overtopping of furrows in the contour tillage system
- overtopping of conservation terraces
- drip zones and stemflow concentration (in forest land)
- grazing sites, browsing sites (in grasslands and savannah)
- urban effects: rooftop drainage, village ground drainage, urban drainage outlets (peri-urban land).
- other man-made or animal influences

Strong variation in general natural erosion conditions on a hillslope scale can be caused by:

- great variation of parent material in case of thin, strongly dipping, strata

- great variation of surface microrelief in case of non-integrated drainage patterns, resulting from a glacial, eolian, solutional (karst), or mass denudational origin of the landscape.
- an irregular soil profile horizonation leading to an irregular depth of a relatively impermeable topsoil. This may occur in relation to different degrees of weathering of dipping layers in the subsoil.
- exposition.

Strong variation in general natural erosion conditions on a hillform scale may be due to dipping strata, or orographic rainfall. Another reason can be differences in the period elapsed since the reclamation for parts of the area, as for instance reclamation from forest (Pissart & Bolline, 1978).

The causes for the non-uniform occurrence of rain erosion can perhaps be grouped in two categories. One containing those effects which can be considered as belonging to the general character of mapping units, on the scales of erosion hazard catchment surveys, and another category which contains the effects which cannot be generalized on those scales. These effects will have to be mapped separately or they will have to be described in the map legend and report as well as possible. (Table 7.4)

Table 7.4 Non-uniform occurrence of rainwater erosion and erosion hazard mapping on catchment survey scales.

TYPES OF NON-UNIFORM OCCURRENCE OF RAINWATER EROSION			
Occurrence that can be generalized for a physiographic soil mapping unit, and be described in the legend / report	Occurrence that cannot be generalized for a soil mapping unit. It has to be mapped separately if scale allows, schematically as follows:		
	Not mappable	1:10,000– 1:30,000	1:30,000– 1:100,000
many, scattered features	small, local features	medium size	large size
BAD SPOTS Local human or animal influence can cause local strong erosion in a land unit of arable land, grazing land, forest land, and peri-urban land, due to the effect of:			
cattle trails, footpathes			trail bundles
roadside furrows and ditches			
camping sites, recreation sites.			
	general overtopping of field boundaries overtopping of contour furrows overtopping of conservation terraces	---	local
drip zones and stemflow (in forest land)			
general overgrazing	grazing sites, in grazing land		
		urban drainage outlets and village ground drainage. (in urban and peri-urban land)	

EROSION PROCESSES with their natural inhomogeneity		
Variable flow patterns of processes of rain-erosion		
LOCAL MOISTURE CONCENTRATIONS Very local areas of saturation even under low rainfall on permeable soils, are explained from three sources:		
	Splash distribution by the effect of surface roughness and local slope concavities	
	the effect of flow immediately below the soil surface	
	the flow in a layered soil, the Topsoil Saturation Overland Flow	
Variation in TOPSOIL (not specified by Soil Subgroup name)		
– within a field – within a mapping unit	– between mapping units which belong to the same legend class, – within a soil classification unit such as a Soil Subgroup of the Soil Taxonomy.	
Variation in general natural EROSION CONDITIONS on hillslope scale		
	Thin dipping strata, strong dip	
Great variation of surface-micro-relief		
An irregular soil profile horizonation with an irregular depth of the relatively impermeable topsoil		
		Orographic rainfall
Variation in general natural EROSION CONDITIONS on relief form scale		
		thick dipping strata, gentle dip
		periods since reclamation for parts of the area

7.5 The erosion toposequence – its role for uniform and non-uniform conditions

The regular or irregular occurrence of rain-erosion may be described by the presence or absence of an erosion toposequence. An erosion toposequence is a series of erosion features and corresponding deposition features, recognized by type and intensity, occurring on a hill from the summit along the slopes down to the drainageway, when this sequence occurs repeatedly in a certain area, along hillslopes of similar shape and substratum influence (Bergsma, 1974). The soil erosion toposequence results from accelerated erosion under human land use in the absence of effective conservation practices.

7.5.1 Uniform conditions

In an erosion toposequence, one can observe zones of different erosion types and intensities which run more or less along the contour in strong relationship with the relief and microrelief, according to the slope inclination and shape and the length of overland flow. On each hillslope, the same sequence of erosion types and intensities will occur when conditions of land use and vegetation and management practices are comparable. This can be studied especially well in the stereophoto-image of airphotos.

An erosion sequence is most apparent in agricultural land and in conditions of fast geological erosion. A sequence is more often observed in arable land than in grazing areas, where the occurrence of the erosion is in addition strongly influenced by the grazing habits of the animals.

Partial erosion toposequences do occur, covering only a part of a hillslope. (17) Their occurrence will depend on differences in substratum, relief, land use or conservation practices on the slope. For example, forested parts may give a good protection or permeable parent materials may reduce the erosion to a low degree in a part of the slope.

The erosion toposequence may serve as a reference for the erosion which can be expected for comparable areas where erosion has not yet progressed very much, because they are as yet under an effective plant cover.The erosion toposequence may serve as a guide to what will happen when land-use changes are considered, such as those which accompany farm improvements, the introduction of conservation practices, reallocation of land and other development activities.

The occurrence of the erosion toposequence will be incorporated in the hazard mapping, if scale permits. This is done at the stage where present erosion is considered for the mapping, as explained in section 3.5.

7.5.2 The absence of the regular erosion toposequence

In many landscapes no regular erosion toposequence can be observed. This is worth noting and understanding the reasons for the absence of an erosion toposequence will increase insight into the erosion conditions of the landscape under study.

In some cases, the absence of the erosion toposequence can be attributed to the frequent interruption of overland flow by field boundaries across the slope, conservation terraces, farm compounds, roads across the slope, etc. They may prevent the development of erosion.

In other situations, a good land cover may prevent erosion. Plots of forest with good ground cover, grass fields and crops that provide good protection during at least an important part of the erosive rainfall in the year can strongly reduce the potential erosion and interfere with a regular erosion toposequence.

In other cases, the absence of the regular erosion toposequence may be attributed to irregular relief, irregular soil pattern, parent material or substratum. An erosion toposequence will not occur when relief forms have considerable variation, where hillslopes have strongly different forms or where the influence of the substratum is different from place to place.

And finally, the erosion toposequence will be absent in situations of very low erosive rainfall or very permeable soils.

Indications of which of the explanations for the absence of the erosion toposequence is the most likely can in many cases be obtained from airphoto study. A large field with clear erosion features may be observed among narrow fields, without erosion, and with their long axis along the contour. A complex substratum may be deduced from local rough microrelief, vegetation and crop growth patterns. Large sloping fields of annual crops where no erosion is observed will point to conditions of low runoff because of low erosive rainfall or high rainfall acceptance.

7.6 The erosion toposequence and overland flow conditions

The erosion features in an erosion toposequence sometimes show an increase of the erosion intensity with the distance from the divide. Reticular wash on nearly level summits may change into directional wash on the upper slopes, grading into clear zones of rill erosion, with gullies on the concave slopes. The gullies may deepen lower down and continue in the gentle footslopes. Sometimes the gullies may decrease in depth on the lower footslopes, while the surface erosion between the gullies becomes very low in these parts. Many other sequences may be found.

In the cases where the erosion toposequence shows a clear increase in erosion intensity with the distance from the divide, the rain-intensities and the rainfall acceptance in that area will be interacting to result in Horton overland flow.

While it was long considered that overland flow generally was of the type of Horton overland flow, generated by rainfall in excess of infiltration rates, it is now concluded to be the dominant type of overland flow only in certain landtypes with rather impermeable soils. Rapid saturation of a shallow permeable part of the soil profile above a relatively impermeable layer or soil horizon is a much more common type of overland flow generation. The last case may be called 'Topsoil saturation overland flow' (Bergsma, 1978). It occurs, for instance, above a ploughpan in the Ap, above an argillic horizon, a spodic horizon, etc.

Overland flow caused by topsoil saturation is a very common case, being frequently responsible for peak flows in rivers. It covers generally only small parts of the landscapes, such as 1 – 10%. The positions where it occurs are:
- nearly-level summits, plateaux and terraces
- hollow slopes (for instance Crabtree and Burt, 1983 about moisture distribution in the hillslope hollow)
- concave slopes and slope parts

These positions can be mapped especially well by airphoto study, as the surface forms are exaggerated in the stereo-image.

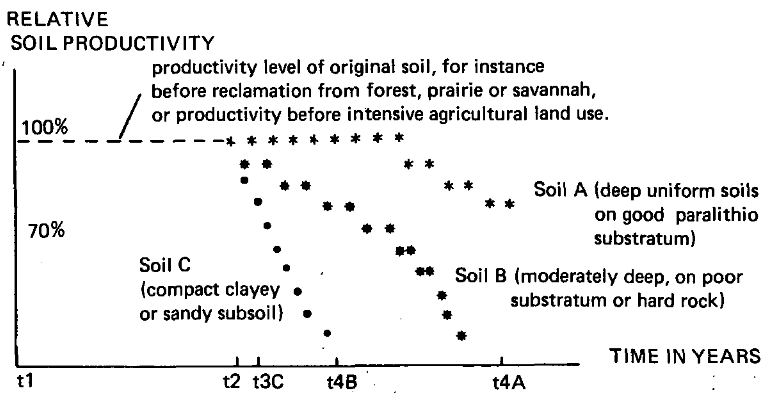
The limited area of occurrence of the topsoil saturation overland flow may cause a regular erosion toposequence to be observed only with difficulty, and in very restricted areas, over short distances. It demands detailed photostudy.

The recognition of the erosion slope length,that is the length of uninterruptedoverland flow, is especially important, because a change of erosion process correlates with the volume of overland flow. Dominance of interrill, prerill, and rill erosion is roughly related to the amount of overland flow, resulting from the rainshowers. Soil losses by splash, interrill and rill erosion increase extremely rapidly; figures such as 1:40:2,000 are given (Morgan, 1979) as relative ratios of soil loss.

In a recent study, Morgan (1983) indicates that the effect of erosivity and erodibility have strong interactions that are locally determined, because the type of shower and the soil profile interact to produce varying volumes of overland flow, which in turn determine the type of dominant erosion process, such as splash, interrill erosion and rill erosion. These processes have a changing relative significance on a site, depending on the rain. For survey, one has to try to find which process or processes are dominant. Roels (1984b and in pers. com.) indicates that there is a limited variation of erosion process on parts of a slope in certain areas.

7.7 Soil erosion and productivity

Soil erosion hazard is evaluated for mapping units following the procedure set out in the previous chapters. The determination of the erosion hazard, is intended to play a role in the land-use planning for sloping areas. The amount of soil expected is by itself, however, not a good guide for conservation planning. Soils affected by the same amount of soil loss show very different productivity decline. The sensitivity of the soil to productivity decline caused by erosion varies greatly for different soils. This is illustrated in Figure 7.3.



Legend t1 time of reclamation into traditional agriculture
t2 begin of intensified agriculture use
t3 begin of serious loss of productivity
t3A for Soil A
t3B for Soil B
t3C for Soil C

Figure 7.3 Erosion progress and productivity decline.

From the diagram, it appears that a certain amount of soil loss causes a different decline in productivity for different soils. This is because soils differ with respect to the soil properties that determine the productivity. It is logical that this plays a role especially in soils with strong contrasting topsoil and subsoil properties. Examples of these soils are: fragipan soils, clayey over sandy textured soils, Alfisols, Ultisols, Spodosols. Soils without contrasting topsoil and subsoil are found in deep Inceptisols and Oxisols.

7.8 Conclusions and remarks

a) The erosion hazard survey records a moment of a development. The trend of the erosion may be to higher rates or lower rates, depending on the stage of development of the natural and accelerated erosion processes.
b) Relief susceptibility to rain-erosion can probably be extrapolated above 25% in classes with boundaries at 40%, 60% and 120%.
c) The recognition of zones of rill erosion hazard is important for focussing on the critical areas of soil loss.
d) If the occurrence of the erosion is 'regular' the recognition and use of the erosion toposequence may be possible and of advantage in mapping erosion and erosion hazard. The occurrence of an erosion toposequence may allow also conclusions on the types of overland flow present in the area.
e) In many cases the occurrence of erosion is not regular, and mapping of erosion hazard by mapping units of a uniform character becomes difficult. Success in mapping will depend on the type of irregularity and the feasibility of mapping these irregularities on various map scales or describing them in the legend.
f) The causes of non-uniformity in the occurrence of rain-erosion are reviewed.
   The effects causing non-uniformity are:
   - bad spots of different origin
   - the erosion processes themselves
   - local moisture concentrations in places such as furrows, concave microrelief and concave slopes.
   - variation in topsoil
   - erosion conditions on hillslope scale
   - eroson conditions on hillform scale
g) The amount of soil loss has to be combined with a measure of productivity decline to arrive at an index of the priority of conservation on agricultural land.

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Discussion

McCormack: Another kind of gully erosion occurs in the United States and has been termed 'ephemeral gullies; they are those which are formed but are subsequently filled up by tillage each year; they are important as the USLE does not predict soil loss caused by these kind of gullies.

Meyerink: Could you comment on the erosion on slopes steeper than 25%.
Bergsma: Measurments were carried out on tea-slopes in Sri Lanka of 15-20% slope; the soil surface was measured up-slope and down-slope of the tea bush during fieldwork in May 1983 and 1984; 2 x 50 points were measured; the relationship shows a cluster of points; the provisional conclusion could be that on slopes between 25-40% the erosion increases with a V2 factor; why V2 factor, because we try to work with a V2 system; on slopes between 40-60% a slight increase in erosion is measured, but at steeper slopes it (the rate of erosion) flattens off; this is somewhat in agreement with Horton's theory; massmovements were discounted as the sites were selected as such.

Flach: Five categories of erosion are used; for planners and policy makers it is important to have some kind of universal measure to apply to research locations; how to combine the five kinds of erosion into one kind of measure.
Bergsma: Yes, this is problematic; but maybe the five kinds are not too bad for the planners and policy makers as the measures that are to be taken to combat erosion are also different; for example conservation measures against gullying are quite different from those for surface erosion.

Flach: True; but for large areas one has to combine efforts to get an idea about the costs involved; so by introducing a monetary unit one could partly solve the problem.

Pussat: The term 'insusceptibility' is used, why not use 'resistance to erosion'.
Bergsma: Resistance to erosion refers, in my opinion, more to the soil properties, while gullying is very much dependent on a certain form of the topography, once that occurs gully erosion will start; on the other hand it is true that the presence of gravel on the surface or gravelly materials this process may be less evident.

Dudal: Although five forms of erosion are differentiated, everything seems to be lumped again when the classes are distinguished in tons/ha; is the distinction between the five forms of erosion maintained and how do you indicate where this erosion actually takes place.
Bergsma: The classes were only used for surface erosion.

van Vliet: What scale of maps are you mainly talking about in this study.
Bergsma: The final scale (which is based on large scale aerial photography) may range between 1: 25,000 and 1: 100,000, and could even be extended to smaller scales.

van Vliet: So for planning purposes the information could be combined to scale 1:250,000 for example?
Bergsma: Yes, correct; procedures are now laid down for a certain scale, one can always reduce (the map scale).

8 Evaluation of agroforestry potential in sloping areas

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Abstract

Eight examples of agroforestry systems in sloping areas are described with two examples of economic analysis of agroforestry systems. The ICRAF diagnosis and design methodology is outlined, exemplified and compared with land evaluation procedures. Distinctive features in land evaluation for agroforestry are that surveys commence with a phase of diagnosis; that the performance of systems, and hence the land-use requirements, cannot be precisely specified at present; and that as a consequence, the output from agroforestry surveys is frequently a research programme. The ICRAF/FAO project, Land Evaluation for Agroforestry, is outlined. Classification of an agroforestry land utilization type as highly suitable for a given area is not related to environment alone but depends on existing land-use systems and problems. The major benefit that agroforestry can bring to sloping areas lies in its capacity to combine soil conservation with productive functions. Agroforestry may often be the preferred form of land use in sloping lands which have problems of soil erosion, soil fertility decline and shortages of fuelwood or fodder. Sloping areas should be a priority environment for the application of research and development in agroforestry.

8.1 Questions

The title of this paper covers three entities: land evaluation, agroforestry and sloping areas. Since relations between two of these, land evaluation and sloping areas, is the subject of this symposium, this leaves two other sets of relationships as the primary questions, namely:

1. How can land evaluation be applied to agroforestry?
2. What benefits can agroforestry offer as a kind of land use in sloping areas?

Anticipating that the answers to these are broadly positive, that is, that agroforestry does have a potential in sloping areas and that this potential can be evaluated, then two further and more specific questions can be asked:

3. Under what circumstances, and in what respects, is agroforestry superior to other kinds of land use in sloping areas?
4. Are sloping areas a priority environment for the application of research and development effort in agroforestry?

8.2 Agroforestry

8.2.1 Agroforestry as a major kind of land use

Agroforestry refers to land-use systems in which trees are grown on the same land as agricultural crops and/or animals, either in a spatial arrangement or a time sequence, and in which there are both ecological and economic interactions between the tree and non-tree components (Lundgren, 1982, modified). Note that 'tree' is here used as an abbreviation for woody plants, comprising trees, shrubs and bamboos.

The second part of this definition, the need for interactions, is an essential feature of agroforestry land-use systems. Economic interactions can mean simply that the tree and the crop (and/or animal) each supply part of the farmers' needs; or could involve, for example, the tree harvest providing capital which is put into improvements to crop production. Ecological interactions are numerous; examples are fertilization with litter from nitrogenfixing trees, feeding of high-protein leaf litter to cattle, the manure from which is then applied to crops, or the soil conservation functions of trees.

Is agroforestry more closely related to agriculture or forestry? Neither. Most agroforestry, probably over 90%, is carried out on agricultural land, and by farmers; as will be illustrated below, the commonest starting point for agroforestry developments is farmland that has problems. Yet it is the distinctive features and functions of trees which are the essence of agroforestry. Given that the concept of a major kind of land use is in any case loosely defined, agroforestry can usefully be regarded as such.

8.2.2 Terminology

Agroforestry components refer to the three elements of a land-use system, the tree (= woody perennial), herb (agricultural crop or pasture plants) and animal. The first two are always present, the last sometimes. This leads to a simple classification of agroforestry systems:

Agrosilvicultural systems:	crops and trees
Silvopastoral systems:	pastures, animals and trees
Agrosilvopastoral systems:	crops, animals and trees (with or without pastures)
Other systems:	e.g. mangrove with fishing, apiculture in trees.

The tree component is almost always a multipurpose tree. After extensive consideration of both concepts and examples it has been found that the land-use system within which a tree is grown is an essential part of this definition. Hence multipurpose trees (MPTs) are those which are grown, or kept and managed, for more than one major purpose (product or service), economically and/or ecologically motivated, in an agroforestry or other multipurpose land-use system (von Carlowitz, 1984, modified). Expressed more simply, multipurpose trees are those which provide more than one significant contribution to the production and/or service functions of the land-use systems they occupy (Huxley, 1984). The main functions of multipurpose trees are listed in Table 8.1.

Table 8.1 Functions of multipurpose trees. Adapted from the ICRAF multipurpose tree data sheet (von Carlowitz, 1984).

Wood	fuelwood (inc. charcoal)
	timber (sawnwood)
	poles (domestic timber)
	other (e.g. carvings)
Fodder	browse } (inc. leaves, seeds, shoots)
	cut-and-carry } (inc. leaves, seeds, shoots)
Food	fruit, nuts
	oils
	beverages
	other edible products
Other products	oils, gums, waxes, dyes, tannin
	fibres, thatching
	latex
	medicinal uses
Services	shade (from sun)
	shelter (from wind)
	soil conservation (inc. reclamation)
	soil improvement
	fencing (= barrier function)
	moisture conservation

Thus the same tree species can be monopurpose where it is managed to optimize one output only, as in a forest plantation managed for timber products; or multipurpose where management is intentionally directed towards two or more outputs, e.g. fuelwood, fodder, shelter, conservation.

Agroforestry practices are the more common arrangements of components in space and time, coupled with the major functions of the tree component. This is more easily illustrated than defined, as in Table 8.2.

An agroforestry system is a set of agroforestry practices within a specified physical, economic and social setting; the land-use system itself may be based on agroforestry, or the agroforestry system may fulfil certain functions within the broader context of the land-use system as a whole. Agroforestry systems are described in terms of their biological, technical, economic and social aspects.

This term, widely employed in agroforestry literature, is so nearly equivalent to the standard definition of a land utilization type that agroforestry system and agroforestry land utilization type may be taken as synonymous. As with land utilization types, existing agroforestry systems are frequently specific to a local region but are potentially extendable to other areas with similar environmental, economic and social conditions.

Table 8.2 Agroforestry practices. Adapted from the ICRAF agroforestry systems inventory (ICRAF, 1983d; Nair, 1984).

Improved tree fallow
Taungya
Alley cropping (hedgerow intercropping)
Boundary planting
Live fences
Multipurpose trees on:
- cropland
- rangeland
- pastures
- homesteads
Woodlots (with multipurpose management)
Trees as shelter for:
- crops (windbreaks, shelterbelts)
- animals
- homesteads
Trees for soil conservation:
- on bunds, terraces
- strips
- hedges
Agricultural tree/shrub crops
- lower-storey tree/shrub crops
- herbaceous crop
- upper storey trees
- pastures and livestock
Aquaforestry (mangrove)
Apiculture with forestry

8.3 Sloping areas and their environments

Sloping areas are here assumed to refer to slope classes c and bc on the FAO/UNESCO Soil Map of the World, that is, areas with dominant slopes over 17°/30% or a combination of this with areas of 5° – 17°/8 – 30%. This paper is largely concerned with sloping areas in tropical and subtropical latitudes.

It may be remarked in passing that the slope classes on the world soil map are not the outcome of a primary inventory of landforms, but are supplementary to classes and map units determined primarily on the basis of soil type. Since there are now also satisfactory world or continental maps of geology, climate and vegetation, the lack of a treatment of landforms at comparable intensity and coverage is deficiency in the inventory of land resources, which could lead to substantial errors in world-scale land evaluation or other estimates of production.

Within the tropics, sloping areas may be grouped on the basis of temperature and altitude into lowland and upland, separated at 1,200 m altitude. These correspond approximately to the division between Köppen A (hot) and B(warm) climates, and between the 'warm tropics' and 'cool tropics' of the FAO agro-ecological zones inventory. On the basis of amount and duration of rainfall, these lands may be further subdivided into humid climates (Köppen Af, Am and Ca, growing period > 270 days), and subhumid climates (Köppen Aw and Cw, growing period 120-270 days). Sloping lands with semi-arid climates are mainly of very low potential and will not be considered. This gives the following classes of sloping land in the tropics and subtropics.

1. Lowland humid tropics

Hot, humid for all or most of the year, vegetation evergreen or semi-evergreen rain forest. Relief commonly either V-shaped valleys with narrow interfluves or convex interfluves, steepening downslope until they pass abruptly into flat valley floors ('demi-orange relief'). Soils are normally ferralsols or acrisols, with nitic properties if on basic rocks.

This is by far the most extensivê tropical sloping-land environment, found in all continents but particularly in Central America, at lower altitudes in the Andean states of South America, in the West and East Indies, the south-east Asia mainland, Pacific islands and eastern tropical Australia.

Common land-use systems in this environment are:

- extractive forestry;
- perennial, non-food crop plantations;
- shifting cultivation of annual food crops, cereals or roots; often with shortened fallow and consequent soil degradation;
- terraced cultivation, including swamp rice (especially in Asia);
- ranching (especially in South America).

The principal environmental hazard is the very reserve rainfall erosivity. Others include rapid oxidation of soil organic matter, high soil acidity with associated P fixation and aluminium toxicity (the last especially, for reasons not well understood, in South America), and rapid leaching. Besides soil erosion, there may be a hazard of accelerated landsliding.

The most common land-use problems are the cutting of rain forest faster than natural or managed regeneration, and shortening of fallows with consequent soil degradation and over-grazing, the two latter sometimes leading to soil erosion. Shortening of fallows is particularly likely in areas which lack the flat valley-floor land that permits swamp rice cultivation.

2. Highland humid tropics

This is a less widespread environment, since most high-altitude regions have a dry season of sufficient length to fall into the subhumid zone. It occurs in parts of the Andes, and the highlands of Malaysia and the East Indies. A high proportion of relief is sloping. Soil become humic ferralsols and humic acrisols at higher altitudes.

Land-use systems are similar to those of the lowland humid zone except that commercial forestry is less common. Land-use problems include shortening of fallows with soil degradation; overgrazing and pasture degradation; and over-cutting for domestic fuelwood and timber leading to reduction in area and species depletion of remaining forests.

3. Lowland subhumid tropics

This is the savanna zone of Africa and the cerrado of South America, with one or two wet seasons (Köppen Aw or Aw' respectively) and at least one long dry season. A high proportion of this climatic region is not sloping, other that on isolated inselbergs. Areas of sloping lands occur, however, particularly in escarpment zones separating erosion surfaces.

Common land-use systems include:
- cultivation of annual crops, often more or less without soil rest periods;
- certain perennial crops, mainly towards the more humid margins;
- extensive grazing (ranging or nomadic);
- afforestation.

Although rainfall erosivity is less than in the humid zone, the soil erosion hazard is almost as high, owing to the slower growth and less complete cover of the vegetation. Drought becomes a hazard in the drier parts of the zone (mean annual rainfall <800 mm). The most widespread land-use problems are first, decline in soil fertility brought about by over-cultivation; secondly, degradation of natural deciduous woodlands through over-cutting with consequent fuelwood shortage; and thirdly, erosion, which is particularly common on grazing land.

4. Highland subhumid tropics

This distinctive environment, sometimes loosely called the 'highland tropics', is extensive in East Africa (especially Kenya and Ethiopia), the Andes and the Himalayas, in the last of which it occurs under a climate of monsoonal origin and regime. Much of this climatic zone is not sloping, being either upland plateau or intermontane basins, but sloping land occurs at the borders of these. Notable examples are the extensive, steeply-sloping and deeply dissected lands of Ethiopia, and the so-called 'foothills' of the Himalayas.

Land-use systems include annual crops, perennial crops in the wetter parts of the zone, grazing and commercial afforestation. Terraced cultivation is common in the Himalayas.

Loss or degradation of natural forests is often considerable, and soil fertility decline and soil erosion are both common. The Ethiopian highlands combine severe soil erosion with almost complete destruction of natural forests. Systems of terraced cultivation have become poorly maintained or abandoned in some areas.

8.4 Agroforestry in sloping areas

8.4.1 Examples

To illustrate the range of agroforestry practices and their potential in sloping areas, eight cases will be described. The first five are existing systems, 'traditional' in the sense of being evolved largely by the farmers of the area concerned, although incorporating some relatively recently introduced crops. The sixth case is a development project, the seventh an example of experimental trials, while the last gives systems suggested in one of the ICRAF collaborative design projects. Two of these examples are drawn from Africa, three from south-east Asia, one from south Asia and two from South America. In these accounts, some added descriptors for land utilization types are employed, explained in Section 6.1 and Table 8.5 below.

1. Terraced hill farming, west Nepal

The first case has been set out as a formal description of a land utilization type (Table 8.3). The Tinau watershed of west Nepal has a lowland subhumid climate, with

Table 8.3 Description of an agroforestry land utilization type: terraced hill farming, Nepal.

Title	Terraced hill farming, western Nepal.
Environment	Lowland subhumid climate (Köppen Aw) of monsoonal origin, 7-8 dry month; slopes steep, 20°–35° (36-70%)
Socio-economic setting	Dense population, severe land shortage, average farm size 1 ha, low income, poor infrastructure
Summary description	Slopes ('bari' land) are terraced, with maize and other rainfed crops on sloping treads, MPTs on risers (contour strips) and farm boundaries (vertical strips) (Figure 8.1).
LUT descriptors	
Outputs	Products: maize and other rainfed annual crops, cattle products, fuelwood. Services: soil conservation.
Market	Dominantly subsistence, plus local marketing.
Capital intensity	Low
Labour intensity	High
Technical knowledge	Of modern agricultural methods, low; moderately amenable to innovations.
Land holdings	Small, average 1 ha; some have separate lowland irrigated rice holding.
Tenure	Owner-cultivated.
Land improvements	Terracing; unlike some other parts of Nepal, terrace treads are initially sloping, older ones becoming level.
Infrastructure requirements	Low; family processing of products; need for road access to local markets.
Power	Ox-ploughing, plus much manual power.
Mechanization	None.
Input level	Low; no artificial fertilizers, mainly local seed.
Cropping	Maize, with subsidiary wheat, finger millet, mustard and legumes. Numerous vegetables and fruit in home gardens. MPTs on terrace risers, over 30 spp.
Cultivation	Ox ploughing, hand weeding. Trees pruned for fodder, cut for fuelwood.
Conservation practices	Achieved through contour terraces, stabilized by trees.
Irrigation	Only on separate lowland fields, for rice.
Livestock	Cattle, buffalos, goats, poultry; for food, cash, draught, manure. Partly stall-fed, partly grazed. Contour tree strips may supply 40-60% of fodder.
Yields	Low; sample survey, maize 930 kg/ha, wheat 580 kg/ha.
Economics	No data.
Agroforestry descriptors.	
Type	Agrosilvopastoral (crops, trees, livestock).
Main interactions	Space, including off-site.
Time	Static, interpolated.
Space	Zonal, row.
AF practices	Main: MPTs for soil conservation, on terraces. other: boundary planting, MPTs around homesteads, live fence.
Functions of trees	Soil conservation, fodder, fuelwood food, fencing.

the excessive concentration of rainfall into four very wet months that is a feature of climates of monsoonal origin. This still further increases the erosion hazard on the steep slopes. Despite the relief, the region is densely populated, and the remaining area of natural forest reduced and degraded. Most farming takes place on sloping land under rainfed conditions, although some farmers also possess a low-lying area of irrigated rice. Whilst giving the appearance of being based on annual crops, chiefly maize, livestock products also play an important role, both for subsistence and cash purposes.

The main agroforestry practice is the planting of trees as strips on two kinds of sites: along the risers of terraces and as vertical (downslope) rows along farm boundaries (Figure 8.1). These rows are quite densely planted and give the landscape a compartmented appearance. Over 30 species are recorded, nearly all having a function as fodder, most also as fuel, and a smaller number as fruit (not to mention the presumable medicinal use of Wrightia antidysenterica). Up to half the livestock feed comes from the tree strips, and there is a further interaction in that the manure from stall-fed animals is returned to the fields. The major service function of the trees is of course soil conservation, through the medium of stabilizing the terraces.
In addition, the tree rows form an effective barrier, permitting livestock to be let into specific fields, and keeping off those of neighbours.

Summarizing the agroforestry features, this is an agrosilvopastoral system (crops + trees + livestock), interacting in space, with the trees zoned, as rows. The main practice is trees on soil conservation works, in this case terrace risers: subsidiary practices are boundary planting and home gardens. The functions of the trees are particularly varied namely fodder, soil conservation, fuelwood, food and fencing. (Source: Fonzen and Oberholzer, 1984).

2. Chagga home gardens, Mount Kilimanjaro, Tanzania

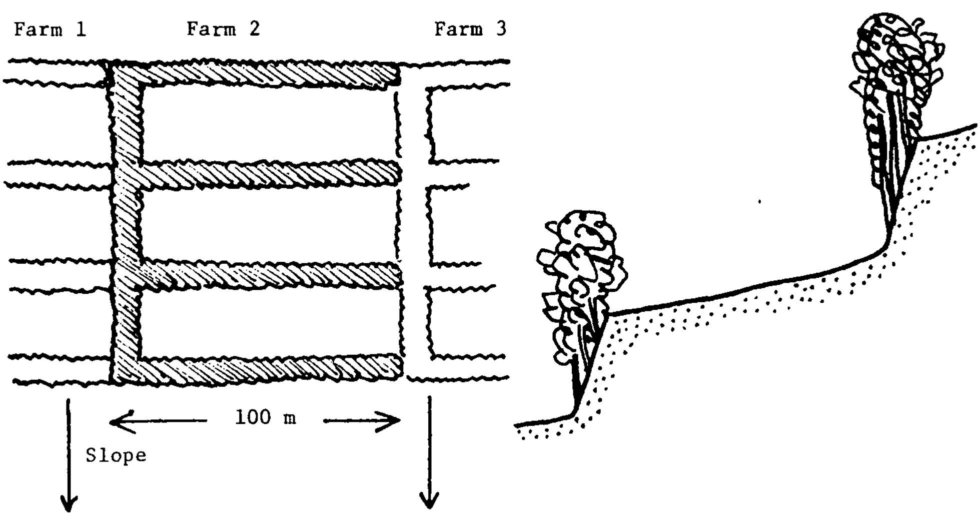

Figure 8.1 Plan view and cross-section of terraced hill farming, West Nepal, After Fonzen and Oberholzer (1984).

This system occupies the south and east slopes of Mount Kilimanjaro, Tanzania, with a subhumid climate and an altitude range extending from lowland to highland. Land is scarce, income low to medium, capital scarce, marketing facilities and other infrasructure moderate. It is a mixed cash and subsistence economy, labour-intensive, owner-occupied.

The home gardens consist of a random and dense arrangement that includes food and cash crops, and herbaceous crops and trees of both plantation (agricultural) species and timber (coffee, others being cardamom, and surplus bananas and food crops. (Figure 8.2) Foodcrops include bananas, maize, beans, root crops, vegetables and fruit. Farmers deliberately retain and manage numerous species of tree (over 40). Cattle and poultry are kept, mainly stall-fed from tree fodder, banana and cultivated grasses.

This system is agrosilvopastoral, interacting in space, static in time and with a mixed, dense multistorey arrangement of the tree and shrub component. As its name indicates, it is an example of the home garden practice, widely found in humid to the moister subhumid environment (cf. e.g. the Kandy home gardens of Sri Lanka, and the example which follows). The trees fulfil productive functions of cash crop income, food, fuelwood and fodder; and besides the soil conservation achieved by the dense, multistorey canopy, there is a substantial element of soil improvement, or maintenance of fertility, through incorporation of leaf litter and manure from stall-fed cattle. (Source: Fernandes et al., 1984).

3. Hillside agroforestry, western Sumatra.
This is a further example of home garden practice, chosen for description as being

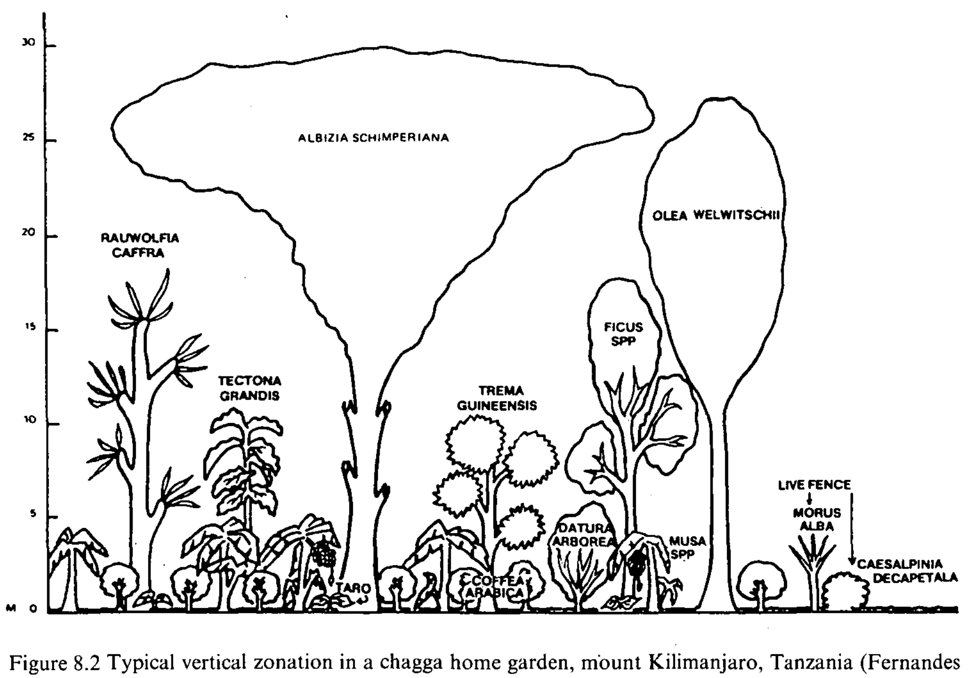

Figure 8.2 Typical vertical zonation in a chagga home garden, mount Kilimanjaro, Tanzania (Fernandes et al., 1984).

in a different continent, a more humid climate and with differences of function. The area around Lake Maninjau, in the central part of west Sumatra, has a lowland humid climate (Köppen Af), with rainfall >3,000 mm and no dry months. As the slopes are very steep, reaching to over 40° (84%), it need hardly be said that the erosion hazard is severe; there is also a serious hazard of accelerated landsliding if the slopes are cleared. The forests which remain have been taken over by the State. The farmers grow swamp rice where possible, in conjunction with the tree gardens of the hillsides.

The gardens are largely multi-storey tree arrangements, with herbaceous crops being only subsidiary. Among the commonest species is the beloved durian, cinnamon, coffee, nutmeg, and many timber species. These are farmed in various combinations, at least partly planned, e.g. durian + cinnamon + timber species. It is an agrosilvicultural system, interacting mainly in space, although gardens are sometimes abandoned or new ones established, giving an element of long-term fallowing. As in all home gardens, the spatial arrangement is mixed and dense. The trees fulfil functions of food and cash crop production, fuelwood and timber production, and erosion and landslide control. (Source: Michon et al., 1984).

4. Coffee-Erythrina-Cordia systems, Costa Rica

Systems of coffee with an upper storey of trees, especially Erythrina poeppigiana and/or Cordia alliodora, are widespread in Central and South America, sometimes on gently-sloping land but often on sloping areas, in part because these provide some of the best sites for coffee. The same two species are also grown with cacao. Such systems are found in humid to the moister subhumid lowland and highland environments. They are exemplified in the vicinity of Turrialba, Costa Rica. The typical socio-economic environment differs from the preceding examples. Land is only moderately scarce, income levels at a low-intermediate level and infrastructure moderate.

The farming system is based on cash-cropping of coffee. Erythrina and/or Cordia are planted in the cropland, in some areas as rows, in others on a mixed, random, open to moderately dense arrangement. Erythrina are pruned several times a year, keeping them as a low stubby life form, and the prunings laid as mulch. Cordia are allowed to grow into tall trees. Erythrina is a nitrogen-fixing tree, and its use for soil fertility maintenance is intentional.

This is an agrosilvicultural system, interacting in space, with the components either in a mixed arrangement or as rows. The functions of the trees are:

Erythrina poeppigiana	Cordia alliodora	Coffee
Shade	Shade	Cash crop
Soil improvement	Timber	
Mulch	Fuelwood	
Soil conservation	Soil conservation	

(Sources: Budowski, 1983; Escalante, in press).

5. Improved tree fallow, Philippines

In Cebu Province, Philippines, a system of improved tree fallow using Leucaena leucocephala (leuco) is found. Although lowland subhumid, it is wet enough (1,620 mm) for rapid growth of leuco. Part of the farm is under crops, part planted to leuco for about three years. The leaf production restores soil fertility. When the trees are cleared, the wood serves two purposes: fuelwood, and to make pegs used in check-barriers to control erosion. The farmers recognize both the fertility maintenance and the soil conservation functions of the trees.

This example is included as a case in which the dominant interaction between the trees and non-tree components takes place in time, as a rotation. (Source: Eslava, 1984.)

6. Alley cropping with soil conservation, Rwanda

The project Agro-Pastoral is a development project in Nyabisindu, Rwanda. The environment is highland subhumid and described as 'mountainous'. Land is very scarce, income very low and infrastructure poor. There are problems of soil erosion, soil fertility decline and deforestation. The efforts to combat these problems by the project include a wide range of methods, only some of which involve trees namely:

1. Afforestation of denuded hilltops and badly degraded farmland.
2. Planting of fruit trees.
3. Planting of fuelwood species along roadside and boundaries.
4. Alley cropping with soil conservation.

In this last practice, trees are planted in field as rows, with 10 m between rows and 3.5–4.5 m between trees, giving a canopy of approximately 10%. They are planned to be felled for fuelwood and replanted on an 8-year rotation. Using Grevillea robusta, 300 trees/ha cut after 8 years are estimated to produce 6 m^3 ha^{-1} per year of fuelwood, enough for one family. Early results from trials of Grevillea have given results that it is hard to believe will be maintained, namely three times the growth rate when planted as tree rows than that from classical afforestation on similar soils. The cropping component is mainly mixed cropping and includes fodder crops, livestock being part of the farming system as a whole. Tree leaves, particularly from the boundary planting where there is a greater variety of species, are cut as fodder.

Thus the farming system as a whole is agrosilvopastoral, with three agroforestry practices and at least six functions of trees. The alley cropping practice has the main functions of soil conservation and fuelwood. (Source: Behmel and Neumann, 1982.)

7. Soil conservation hedges, Philippines

Distinct in appearance from the previous example of alley cropping, although fulfilling the same functions on sloping land, is the practice of leuco conservation hedges tested under experimental conditions in the Philippines. The environment is lowland humid, and the socio-economic context one of moderate levels of land shortage, income and infrastructure. Leuco is planted as narrow hedges, sown very close; in the experimental example described, spacings of 10, 15 and 20 trees per metre were tried. They are pruned several times a year, keeping the form of a low but dense hedge, 30 – 50 cm high; prunings are laid on the soil around intervening crops. As has commonly been found desirable with leuco fertilization, low levels of artificial fertilizer should be added for best results. In one rather extreme experimental trial, leucaena hedges 1.5 m apart were planted alternately with single rows of maize, with a control plot of maize only. The yield per plant was 70 g with leuco as against 49 g with maize only, but owing to the larger number of plants in the control there was no significant difference between total yields (in the short term), at 2.5 t ha^{-1}. The ICRAF collaborative project with Philippines recommended a similar system, with its dual functions of soil conservation and fertility improvement. Designing a research programme to test the system, it is recommended first, that trials should be conducted with 1.5, 3, 4.5 and 6 m spacings between hedges, and 1 – 5 intervening rows of maize; and secondly, that studies should be made to see if cash crops could be included in the hedgerows, namely black pepper, ginger and pineapples, thereby increasing the number of functions. (Sources: de la Rosa, n.d., and Torres et al., 1984.)

8. Design of agroforestry practices for Pucallpa, Peru
The final example to be given consists of the recommendations of the ICRAF collaborative project with Peru. Since this illustrates also the ICRAF diagnostic and design methodology, it will be described in the following section. It is listed as a case study also, partly so as to include the only example of sylvopastoral practices reported.

8.4.2 Summary

Table 8.4 is a summary of the eight examples described. It has no statistical value, but illustrates first, the range of agroforestry practices commonly found in sloping areas, and secondly, the most common functions fulfilled by the tree component.

Eight practices are represented, with three variants of trees for soil conservation. Of these, tree fallows, plantation crop combinations, boundary planting, live fences and MPTs on pastures might equally be found on non-sloping lands, the last-named more commonly so. Alley cropping systems can be designed for non-sloping areas, where they would be directed towards soil improvement, fuelwood and/or fodder; but where found on sloping lands, they are intentionally designed with soil conservation as a major function. The various conservation practices are clearly of greatest applicability in sloping areas, whilst tree gardens are one way of creating a sustainable and productive system on land which would otherwise have a severe erosion hazard.

Of the various functions of the tree component, only that of soil conservation is specific to sloping lands. The other functions are those inherent in multipurpose trees and thus agroforestry systems. The fact that fuelwood provision and soil improvement appear so frequently reflects the problem-solving aspect of agroforestry: both are problems typical of sloping areas in which the initially high soil fertility, perhaps coupled with socio-political factors, has led to high population with consequent problems of over-cultivation and forest clearance.

8.5 Related methods

8.5.1 General

The preceding descriptive accounts give a qualitative indication of the benefits that agroforestry can bring, or in some cases that it is hoped it can bring, to problems of land use in sloping areas. They do not answer two of the key questions in land evaluation, namely which are the best sites for any specified land utilization type, and which is the best kind of land use on any given site?

It should be said once that ICRAF is not yet able to offer firmly based answers

Table 8.4 Characteristics of eight agroforestry systems on sloping areas. For explanation of terms, see Tables 1, 2 and 5.

	Feature	Nepal	Tanzania	Sumatra	Costa Rica	Philippines (1)	Rwanda	Philippines (2)	Peru
Type:	Agrosilvicultural			✓	✓	✓		✓	
	Silvopastoral								✓
	Agrosilvopastoral	✓	✓				✓		✓
Interactions:	Space	✓	✓	✓	✓		✓	✓	✓
	Time					✓			
Practices:	Improved tree fallow					✓			✓
	Alley cropping						✓		✓
	Boundary planting	✓					✓		
	Live fences		✓						✓
	MPTs on pasture								✓
	Conservation: terraces	✓							
	strips						✓		
	hedges							✓	
	Tree gardens		✓	✓					
	Plantation crops with trees				✓				
	Shade		✓		✓				
Tree functions:	Fuelwood	✓	✓	✓	✓		✓		
	Timber		✓	✓	✓				
	Fodder (cut)	✓	✓						
	Food	✓	✓	✓					✓
	Cash crop		✓	✓	✓				
	Soil conservation	✓	✓	✓	✓	✓	✓	✓	✓
	Soil improvement		✓		✓	✓		✓	✓
	Fencing	✓							✓

to either of these questions. Perhaps surprisingly, to the present audience, it has not so far applied the standard procedures of land evaluation to its field projects. Instead, these have been based on a set of procedures known as the diagnosis and design methodology. This latter has many points of contact with land evaluation; indeed, it is thought possible that the two sets of procedures may prove to be convergent when applied in similar circumstances. A brief outline of the diagnosis and design approach is therefore a necessary preliminary to considering how land evaluation can be applied to agroforestry.

One aspect of evaluation, namely analysis in economic terms, has been applied to agroforestry systems, and some examples of this are also given.

8.5.2 Agroforestry diagnosis and design

The diagnosis and design methodology is one of a family of 'farmers first' approaches to rural land development. Its ultimate purpose is to design agroforestry land-use systems which will help to solve the problems of rural land use. However, since the technology of agroforestry is in many cases not fully proven, the proximate objective is usually to design a research programme that will test systems which are believed to have this problem-solving potential.

Diagnosis and design is a methodology of some complexity, to which the present very brief summary cannot do justice. Those who are interested are urged to discover more about it, from the following:

- Guidelines for agroforestry diagnosis and design (ICRAF, 1983a). A 25-page summary of the approach, including an outline of procedures as 12 steps. This might be compared with the Framework for land evaluation (FAO, 1976).
- Resources for agroforestry diagnosis and design (ICRAF, 1983b). A 383 page vademecum of procedures, including proformas. Comparable with the Guidelines on land evaluation for rainfed agriculture (FAO, 1983).
- Technology and research considerations in ICRAF's 'diagnosis and design' procedures (Huxley and Wood, 1984). Amplifies the technology design stage of procedures.
- One or more examples of application of the methodology. Comparable with reports on land evaluation studies. Those at present most accessible are based on Kenya (Raintree, 1983; Hoekstra, 1984a) and the Philippines (Torres et al., 1984).

In barest outline, the phases in a diagnosis and design study are:

1. Diagnose the land-use problems of an area.
2. Formulate agroforestry land-use systems that have the potential to ameliorate those problems and which are sustainable and adoptable.
3. Design a research program which will test and optimize these systems.

These phases lead potentially to a fourth, in which the improved and tested systems are implemented in the area through a programme of extension and development.

Set out in slightly more detail (but still simplified) the steps become:

1. Identify and describe the land-use systems with the study area. A land- use system has the same meaning as in land evaluation terminology, namely a combination of a land unit with a kind of land use. This is an initial stratification of the study area, the remaining phases being applied potentially to each of the land-use systems

but in practice, to those which have the most serious problems and/or the greatest apparent scope for agroforestry assistance.

2. Conduct a diagnostic survey of the problems faced by farmers, or other land users, in the area. These may be supply problems, that is, shortfalls in the farmers' needs for food, fuel, shelter, cash, capital and social needs; or sustainability problems, e.g. soil erosion, pasture degradation, reduction in area of forests. Although the farmers are the focus, the land itself may also be regarded as having problems.
3. Analyze the causes of these problems. This is done by a causal network in which some of the initiating factors are socio-economic whilst others derive partly or mainly from the physical environment. Examples of causal chains taken from such networks are:

Land scarce → reduction in length of fallows → decline in soil fertility → low crop yields → food shortage

Land scarce	→	cultivation of steep slopes	→	soil erosion	→	low crop yields
Seasonal decline in feed quality	→	low animal productivity	→	low cash income		
Rainfall variability	→	recurrent crop failure	→	recurrent food shortage		
Population growth	→	destruction of forests	→	fuelwood shortage		

More complex relationships, including branching or Y-shaped chains and feedback loops, are also examined.

4. Derive specifications for systems suited to the area. These must: 1. have the capacity to ameliorate some of the identified problems, through interventions in the causal networks; 2. be sustainable; 3. be adoptable, that is, within the financial and technical capabilities of the farmers, implementable within the available (or a modified) infrastructure, and acceptable to them (i.e. 'if...would you try this?').
5. Based on the system specifications identify technologies which appear to have potential to make a contribution. These may include both agroforestry and non-agroforestry technologies; the report on the study draws attention to the latter, but does not proceed further with them.
6. Analyze the candidate agroforestry technologies and select the most promising from among them. Based on these, design a land-use system which, if it works, will help to solve the problems.
7. Make a preliminary ex ante evaluation of this land-use system, including environmental, economic and social aspects.
8. Decide what is known with confidence about the functioning of the proposed system, and what needs to be tested through research. Those elements, if any, about which there is reliable information can immediately be recommended for adoption.
9. For the remaining elements, design a research programme which will test the functioning of the proposed systems, and so lead to their improvement. This usually consists of a combination of on-farm research and on-station research.
10. Make the necessary institutional arrangements for implementing the research programme.

Stages 8 and 9 incorporate a three-way switch, between implementation, on-farm research and on-station research. Immediate implementation can be embarked upon where technological elements which make up a proposed system are adequately proven. On-farm research is appropriate where the technology is less firmly proven, but the consequences to the farmer if it goes wrong are not too serious (e.g. boundary planting of fruit trees); it should also be adopted where there remains an element of doubt about the capacity or willingness of the farmers to put the system into practice. On-station research has numerous functions, for example, the testing of unproven technologies, species and provenance trials of multipurpose trees, or specialized studies of particular elements, such as pruning practices on soil moisture competition.

8.5.3 Diagnosis and design: an example

The diagnosis and design procedure may be illustrated from one of the two areas, the most steeply sloping, in the ICRAF collaborative programme in Peru. The following account is necessarily highly simplified.

The Pucallpa region lies in the Peruvian section of the Amazon Basin, latitude 8°30'S, altitude 250 m. It has a lowland humid tropical climate (Köppen Am) and rain forest vegetation; strongly acid acrisols are the dominant soil type, and slopes are moderate to steep. The main land-use systems are fallow-based cultivation of upland rice and cattle ranching.

The main problem of the upland rice system is low crop yields brought about by a combination of low inputs with progressive shortening of the fallow period. On those farms for which land area was limited, the cattle ranching system suffered from low productivity of the natural pastures. A further problem common to both systems was shortage of capital for investment in improvements. Constraints to the design of interventions were that they should have low capital requirements; not make use of inputs inaccessible to farmers; and be consistent, in the case of cash crops, with marketing potentials of the area. The constraint of capital shortage prevents adoption of the high-input systems developed for annual cropping at the Yurimaguas Research Station (e.g. Valverde and Bandy, 1982).

For the cattle system, one improvement which meets all the specifications is not agroforestry, namely pasture improvement and development of productive and persistent legume-grass associations. Possible agroforestry improvements are:
- improved tree fallows, based on N-fixing trees;
- as an alternative to this, alley cropping with N-fixing trees, using a design which combines soil conservation;
- an increase in the number and variety of fruit trees, for extra cash income;
- substitution of a herbaceous shrub in legume-grass pastures, as a way of trying to avoid competitive exclusion problems common to such mixtures;
- live fences on pastures, permitting some degree of pasture rotation.

Of these possibilities, that of forest trees requires first, assessment of environmental suitabilities and secondly, study of marketing potential. If these can be completed, implementation can begin quite soon. The remaining practices are not well tested for this environment, and a substantial programme of on-station research is recommended. (Source: Torres and Raintree, 1984.)

8.5.4 Economic analysis of agroforestry systems

As with the treatment of social aspects, economic analysis of agroforestry systems may be said to have reached a more advanced stage than evaluation in relation to environment. A recent bibliography lists 90 such economic analyses (Hoekstra and van Gelder, 1983). A computer software package has been developed, MULBUD, which enables the user to model and analyze agroforestry systems (Etherington and Matthews, 1982). It should be made clear that as the package stands at present, all data on crop and tree performance, yields, etc., is input by the user; there is no element of biophysical modelling.

Two examples may be given. A recent collaborative project between ICRAF and Malaysian institutions led to a design for an agroforestry system for moderately-sloping dissected lowland, with a humid climate, on dissected lowlands north-east of Kuala Lumpur. This differs from the examples previously described in that it was designed for land presently in, and intended to remain as, forest reserve. In part because the main aim was to produce fast-growing softwoods, and in part owing to a constraint set by the Forestry Department, that perennial agricultural crops could not be planted, the design was directed towards modications of the taungya system. Two variants were produced, both based on combinations of the planting of fastgrowing timber trees with annual crops during the first year, sheep grazed beneath the trees for a further period, then trees only when their crown cover becomes dense. The farmers move to a new area each year, felling the secondary jungle, planting annuals plus trees, and tending the latter. Unlike most taungya systems, in which the dominant interaction takes place in time, this design involves substantial spatial interaction as well. (There are reservations concerning these designs, but these need not be discussed here.)

Two variants of this system were analyzed on the MULBUD package: a mixed system in which the trees were regularly spaced, and a zonal system in which the trees were planted as broad belts along the contour. These were compared with a straightforward timber plantation, using existing methods of the Forestry Department. The results are expressed in two ways: returns per unit area of land, as net present value in Malaysian dollars per hectare over a 15-year cycle; and as costs per unit volume of timber produced, in Malaysian dollars per cubic metre. The first is relevant from the national aspect of maximizing land productivity, the second from the point of view of the Forestry Department for which costs, and not land, is the primary limiting factor.

Land-use system	NPV, M\$ ha^{-1}	Timber cost M\$ m^{3}
Timber plantation	7960	9.15
Agroforestry, mixed system	11030	
of which forestry component	8470	7.33
Agroforestry, zonal system	7130	
of which forestry component	4000	9.00

The differences between agroforestry and forestry are not dramatic in economic terms; but given that there are strong social pressures to allow farmers to have a stake in this area, the economics are sufficiently promising, even from the partial point of view of the forestry component alone. The major saving to forest operations lies in lower establishment costs. In the mixed model there is no loss of timber and a gain from the crop and livestock elements; in the zonal model, the latter compensates for a lower timber yield and revenue. (Source: Hoekstra, 1984b.)

The second example is unusual among economic analyses in that it includes an element of environmental differentiation, based on different tree growth rates for rainfall regions. It is taken from a study by the Beijer Institute of the fuelwood supply and demand projections for Kenya (Openshaw, 1981). The agroforestry model is based on achievement of a 15% crown on farmland, without loss of crop production, yielding 4.5 m^3 ha^{-1} per year in the high rainfall area and 2.6 m^3 ha^{-1} per year with medium rainfall. There is a sensitivity analysis of different assumptions for labour rates and fuelwood prices, but taking the same set of assumptions for each case, the internal rates of return are as follows:

Land-use system	Ranfall region	IRR %
Fuelwood plantation	High-medium	9,5
Taungya system plantation	High-medium	14,5
Trees on farmland (agroforestry)	High	29
Trees on farmland (agroforestry)	Medium	17,5
Peri-urban plantation	Medium-low	4,5
Industrial timber plantation	Hig	13,5
Industrial timber plantation	Medium (low alt.)	8
Fuelwood from natural forests	High	54

Agroforestry comes out as markedly superior to various forest plantation systems. This is just as well, for it makes an economic virtue out of a practical necessity: Kenya's semi-arid lands do not possess the growth potential to satisfy its projected fuelwood demands, whilst its humid lands (many of which are sloping) are fully occupied by farmers. The highest return, as would be expected, comes from using natural forests, but the incremental growth from these falls considerably short of fulfilling even present-day fuelwood demands.

8.6 Land evaluation for agroforestry

8.6.1 Modifications to procedures

With the above account of diagnosis and design methods as a background, coupled with field experience of agroforestry projects, let us review the procedures of land evaluation, pointing out to what extent they appear to need special treatment when applied to agroforestry. The diagram of procedures in Land evaluation for forestry (FAO, 1984) will be taken as a basis (Figure 8.3). As compared with that in the rainfed agriculture volume this has an added box, 'Economic and social data: collection, analysis'. Note should also be taken of the three points for input of economic and social data given in the forestry volume (Page 94), namely at the stages of determination of objectives, formulation and refinement of land utilization types, and economic and social analysis in the comparison of land use with land.

Planning the evaluation: objectives'

Right at the beginning of land evaluation procedures comes the first major point of difference. The Framework and its successor volumes basically assume that the objectives of the survey are known before fieldwork starts, and can be established by preliminary discussion, 'between ... agriculturalists, engineers, economists, sociologists, planners, government officials' (oh, and also) 'representatives of the local population likely to be affected' says the Framework airily.

The first feature of agroforestry is that the objective is often problem-solving: that is, advice on the potential of agroforestry is called upon for an area which has land-use problems. Most commonly, these are soil fertility decline, soil erosion, fuelwood shortage (actual or projected) or pasture degradation.

Secondly, a fundamental principle is that diagnosis must precede treatment. That is, given that an area is known to have land use problems, a substantial period of field survey is necessary in order to find out in detail the nature of these problems and analyze their causes. There is no such principle in the Framework.

'Land utilization types: formulation and description'

A feature of agroforestry land utilization types is that they are often conceived and formulated as interventions into the existing land use, usually agriculture. Thus the approach is predominantly that of improvement rather than transformation. Closely related is the fact that practicability and acceptability is built into the proposals at an early stage. This avoids the subsequent problem of 'We've done the research: now how are we going to get the farmers to accept the system?' Based on the diagnosis of the present land-use system and the constraints under which the farmers are operating, acceptability is built into the design of the proposed agroforestry systems. There is no reason, of course, why this should not be done for non-agroforestry land utilization types.

'Land utilization types: description'

The standard list of descriptors for land utilization types (outputs, market orientation, capital intensity, etc.) are almost identical in the guidelines on rainfed agriculture and on forestry, apart from minor changes in wording, e.g. cultivation practices/silvicultural practices. The same list appears in the guidelines on irrigation with the addition of headings specific to water management. All of these descriptors are relevant to agroforestry systems, as has been illustrated in Table 8.3. In the current world inventory of agroforestry systems being conducted by ICRAF, care was taken to include each of them in the computerized summary of characteristics.

There are, however, additional features that are of particular significance in the description of agroforestry land utilization types. These could indeed be included under the standard headings, Outputs, Cropping characteristics and Cultivation/Silvicultural practices, but as they define the essential distinguishing features of agroforestry, namely the tree/non-tree interactions and the roles of the tree component in the land- use system as a whole, it is better to isolate them as a separate set of descriptors, as in Table 8.5.

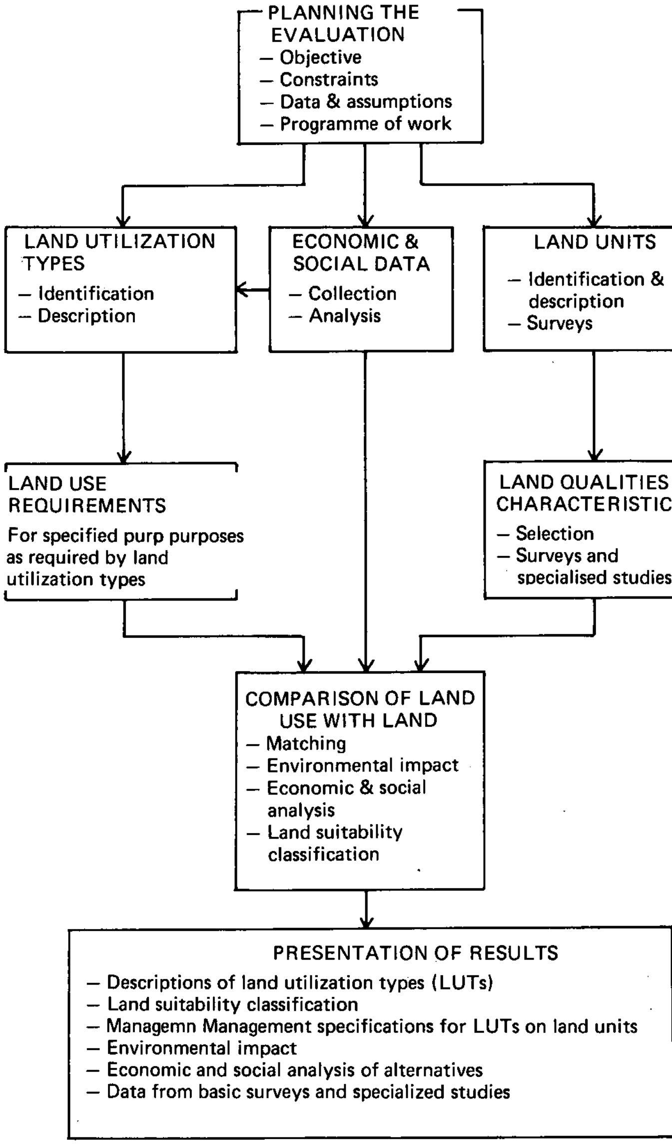

Figure 8.3 Procedures in land evaluation. After FAO (1984, p. 27). As compared with the source, an aro arrow has been added showing the use of economic and social data in the formulation of land utilization types.

'Economic and social data'

No special features for data collection. Data are incorporated into objectives and design of land utilization types as well as during comparison of land use with land.

'Land units'

No special features.

Table 8.5 Descriptors for agroforestry land utilization types. Based on Torres (1983), Huxley (1983) and the ICRAF agroforestry systems inventory.

Type of system	Agrosilvicultural, silvopastoral agrosilvopastoral, other (see Section 2.2)
Dominant interaction (between tree and non-tree components)	Space: trees and other components are grown simultaneously, in a spatial arrangement. Time: trees follow crops or pasture in a rotation. Both: the system includes substantial interactions in both space and time.
Arrangement in space	Mixed, dense (e.g. home gardens) Mixed, sparse (e.g. most systems of trees in pastures) Row (single line of trees) Strip (belt more than one tree in width) Boundary (trees on edges of fields roads, etc.) Block (as in tree plantations)
Arrangement in time	Coincident Concomitant Overlapping Separate Interpolated (Time-dominant systems are necessarily separate; space-dominant systems with annual crops are usually interpolated; with perennial crops may be in various time arrangements).
Agroforestry practices	See Table 8.1
Functions of the trees	See Table 8.2

'Land-use requirements'

Performance of agroforestry utilization types is often not known, hence neither are precise land-use requirements. To meet this situation, there is need for a period of research, and hence design of a research programme.

'Land qualities and characteristics'

No qualities or characteristics additional to those applicable to agriculture and forestry have been found necessary. This applies to qualities for management and conservation as well as those for plant growth.

'Comparison of land use with land'

Physical requirements	Not precisely known, see above.
Environmental impact	Important in agroforestry sytems; information available.
Social analysis	Important in agroforestry systems; methods available.
Economic analysis	Methods available; has been done many times, on an ex ante basis.
Land suitability classification	Has not yet been attempted.

In summary, the main differences between land evaluation methods as set out in the FAO guidelines for rainfed agriculture and forestry, and those practised in, or appropriate to, the evaluation of agroforestry systems are:

1. The objective is often problem-solving.
2. Surveys commence with a stage of diagnosis of problems and their causes.
3. To describe agroforestry land utilization types, a set of additional descriptors is needed.
4. The performance of agroforestry systems, in relation to land qualities, is frequently not firmly established, and thus the land-use requirements cannot be precisely specified.
5. In part due to the uncertainties over performance, the output from agroforestry studies is frequently a design for a research programme, incorporating on-station and on-farm research, together with a variable element of immediate implementation.
6. In agroforestry surveys to date, there has been a relatively greater emphasis on social features and less on environmental features, as compared with most land evaluation studies.

8.6.2 The ICRAF/FAO Project, Land Evaluation for Agroforestry

Recognizing that there is a need to apply methods of land evaluation to agroforestry, and that simple adaptation of existing methods will not be sufficient, ICRAF has embarked upon a project in land evaluation for agroforestry (with the serendipitous acronym of LEAF). It has been fortunate to secure the technical cooperation of FAO in this activity. The rationale for the project as a whole has been set out in a Working Paper, Land Evaluation for Agroforestry: the tasks ahead (Young, 1984). The necessary stages in the development of such a methodology are as follows:

1. An environmental data base.
2. The formulation of appropriate land utilization types, as a basis for suitability analysis.
3. Land-use requirements, for agroforestry components (trees, crops, livestock) and technologies.
4. Biophysical models of interactions between trees and other components of agroforestry systems.
5. An assessment of the environmental impact, and hence sustainability, of agroforestry systems.
6. A methodology for comparison between agroforestry and other land-use systems, on a given site.
7. Case studies to test the above.
8. The holding of an international workshop.

No specific research needs are included for economic analysis nor for the examination of social impact, since satisfactory procedures for these aspects already exist.

8.6.3 The ICRAF environmental data base

Since it is the particular interest of land evaluation, brief details may be given of the environmental data base of information on agroforestry. Further details, with examples of computer outputs, are given in Young (1983 and 1984).

There are two main files to the data base, a sites file and a requirements file. The sites file contains records of the complete range of environmental conditions to be found as sites associated with agroforestry. These include locations of ICRA's collaborative research programme, sites of existing agroforestry systems and sites of agroforestry experimental work. The fourth kind of site that can be entered is any area of interest to a user. By storing all such data in a standardized form, it will be possible to identify and compare sites with similar environments.

The requirements file is intended to store the environmental requirements of agroforestry components and land utilization types. At present it contains only requirements of multipurpose trees. Crop requirements will be added by assembling data from FAO and other surveys. In course of time it is hoped to include the environmental requirements of agroforestry land utilization types, but that achievement is some way in the future.

A diagram showing the structure of the environmental data base, together with an explanation of the structure of the requirements file and examples of outputs, is given in Young (1984, Figure 3 and Tables 1 and 2).

8.7 Discussion and conclusions

The four questions posed at the outset can now be reviewed in the light of the information presented.

8.7.1 How can land evaluation be applied to agroforestry?

The first question is the adequacy and appropriateness of existing procedures of land evaluation when applied to agroforestry. The standard descriptors for land utilization types are all applicable, but need to be supplemented by aspects distinctive to agroforestry systems; the origin of these aspects lies in two features of such systems, the interaction between the tree and non-tree components and the multipurpose role of the trees. Comparison between land and use can already be achieved satisfactorily in terms of environmental impact, social aspects and economic analysis. It can only be carried out for physical requirements on a generalized basis, owing to lack of sufficient performance data for agroforestry systems in relation to environmental conditions. This situation means that in many cases, the output from an agroforestry study is a combination of a research programme combined with a variable amount of direct implementation.

There is a further aspect. It seems likely that the classification of a particular agroforestry land utilization type as highly suitable for a given area is not related to the environmental conditions of that area alone; it depends to a substantial extent on the existing land-use systems in the area and their problems. For example, an agroforestry practice that combines soil conservation with fuelwood production is highly suitable for a certain area not only because its land has a high erosion hazard but also because of a fuelwood shortage among its people.

A consequence is that, in the author's present perception, the 'Guidelines on land evaluation for agroforestry' will not be simply an adaptation, following the same outline, of the guidelines for rainfed agriculture, forestry and irrigated agriculture. There are likely to be some substantial modifications in principles and procedures, possibly including some element of integration with the diagnosis and design methodology. This question is further discussed in Young (1984).

8.7.2 What benefits can agroforestry bring to sloping areas?

Generalizing from the examples in Section 4, there are a range of benefits, provided that the agroforestry practices and systems are based on sound design and their performance is proven by trials. The major element is that sloping areas invariably have a substantial hazard of soil erosion, and well-designed agroforestry has the capacity to combine conservation with productive functions. Since fuelwood production is the most commonly called-for output from multipurpose trees, then insofar as sloping areas have an inherent tendency towards a situation of fuelwood shortage, then agroforestry has a further role in this respect. More generally, whereas crops present serious problems for cultivation on slopes, trees do not, leading to potential benefits from making use of interactions between the two.

8.7.3 Under what circumstances is agroforestry likely to be the preferred form of land use in sloping areas?

Converted to the approach of land evaluation, the third question could be expressed as follows: if for a sloping area, a land evaluation were conducted which included one or more systems of agriculture, agroforestry and forestry, under what circumstances would agroforestry be classified as more highly suitable?

Suppose that a watershed fulfilled an important role as a water catchment, that it was presently uninhabited, and that there was no strong land pressure in the area; then clearly, the preferred use would be to retain that watershed under protective forestry. It is harder to conceive of a set of circumstances in which agroforestry should be equally clearly excluded in favour of agriculture, but perhaps a well-maintained system of terraced rice fields, their fuelwood and fodder needs adequately provided from other nearby land, would qualify – if such a case exists.

The circumstances in which agroforestry appears to have the potential to make a considerable contribution to the welfare of the people is in those sloping lands of the humid and subhumid tropics which suffer from one or more of the problems of soil erosion, over-cultivation and soil fertility decline, or shortage of fuelwood or fodder. These are land-use problems which agroforestry, with its particular capacity to combine productivity with sustainability, has special potential to ameliorate.

8.7.4 Should sloping areas be a priority environment for application of agroforestry research and development effort?

From the two preceding subsections, it is apparent that the answer to this final question is a clear 'Yes'. Sloping areas frequently have problems of land use of the kinds that agroforestry can assist. Clearly, therefore, this should be an environment towards which effort is particularly directed. It would go beyond the scope of this paper to carry out a comparative review of other environments, but it appears possible that there are none in which the combination of need with potential for improvement is so clearly present.

There is some more or less independent confirmation of this situation. The ICRAF collaborative programme is one in which agroforestry research is carried out by institutions in a network of countries, with ICRAF playing a role in design and coordination. The programme is based on the diagnosis and design methodology, applied to selected target areas. These areas have not been chosen by means of land evaluation surveys. They are selected primarily by the collaborating countries, on grounds which vary in detail but which are broadly that they possess land-use problems which it is thought that agroforestry could assist. To date there have been eight such study areas. Of these, only one is classed as gently sloping; two are moderately sloping whilst four include areas of both moderate and steep slopes. The most recent, the Bhaintam watershed for the Himalayas is Uttar Pradesh, India, has been covered by a survey of slope class; 92% of the watershed has slopes over 19° (34%), i.e. steep, whilst 56% has slopes over 27° (50%) and 6% at over 45° (100%)!

There is no doubt an element of chance in this concentration of requests for collaborative assistance on sloping lands, but it is strongly indicative. Among requests to the recently-formed ICRAF Advisory Unit, those from sloping areas again appear, for example areas in Rwanda and Indonesia.

8.8 Design, research and implementation

It is well to end on a note of caution. Great as the potential benefits of agroforestry to sloping lands may appear to be, it would be unwise in most cases to proceed with immediate large-scale implementation. Whilst some traditional agroforestry systems have been functioning successfully for many years, most modern designs for introductions have been subject to only a limited degree of testing – and still less to testing under specific local environmental conditions. Hence the way ahead that is normally to be recommended at the present state of technology is a well-designed research programme, tailored to the needs of the area and incorporating both on-station and on-farm research, coupled with a limited amount of immediate implementation.

If an introduced agroforestry technology system is to be successful, it is necessary to ensure:

1. That the trees selected will grow well in the area. This is a fundamental requirement, without which all other functions of agroforestry will fail.
2. That the system is well designed. The attitude 'trees are wonderful, plant them' is not enough. Trees alone do not even achieve soil conservation: it is the design which they are planted and the subsequent management that matters (Wiersum, 1984).

Every aspect of proposed agroforestry technologies need to be subject to careful analysis, to minimize adverse interactions and to obtain the desired balance of beneficial functions.

3. That the system has been tested: The design must be tested under controlled field conditions; if it has been found satisfactory in other regions, trials are necessary under local environmental conditions (and with locally realistic inputs and management practices). This imposes a delay of some 5 years, but implementation of an unproven technology which fails can cause an equal delay, at considerably greater cost.
4. Finally, that the system meets the needs of the people. That is, the research programme itself should be designed such that its output is a set of technologies, or one or more agroforestry systems, that is adapted to the environment of the area, helps to ameliorate its land-use problems, and can be implemented by, and is acceptable to, its people.

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9 Soil erosion loss monitoring and prediction under semi-arid agriculture in the Peace River Prairie Region of NW Canada

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9.1 Introduction

In Canada, the importance of land degradation and conservation in regard to land use and land evaluation was officially recognized in 1978 within the Federal Department of Agriculture with the reorganization of the Soil Research Institute into the Land Resource Research Institute. Under the Land Use and Evaluation Section of the newly structured institute, a national program on Land Resource Protection commenced, including land degradation studies in relation to soil and water quality. It was also recognized that a major cause of land degradation is soil erosion (Coote et al., 1981). One aspect of this national program deals with soil erosion monitoring and prediction in the Peace River Region of N.W. Canada (Figure 9.1), an area with

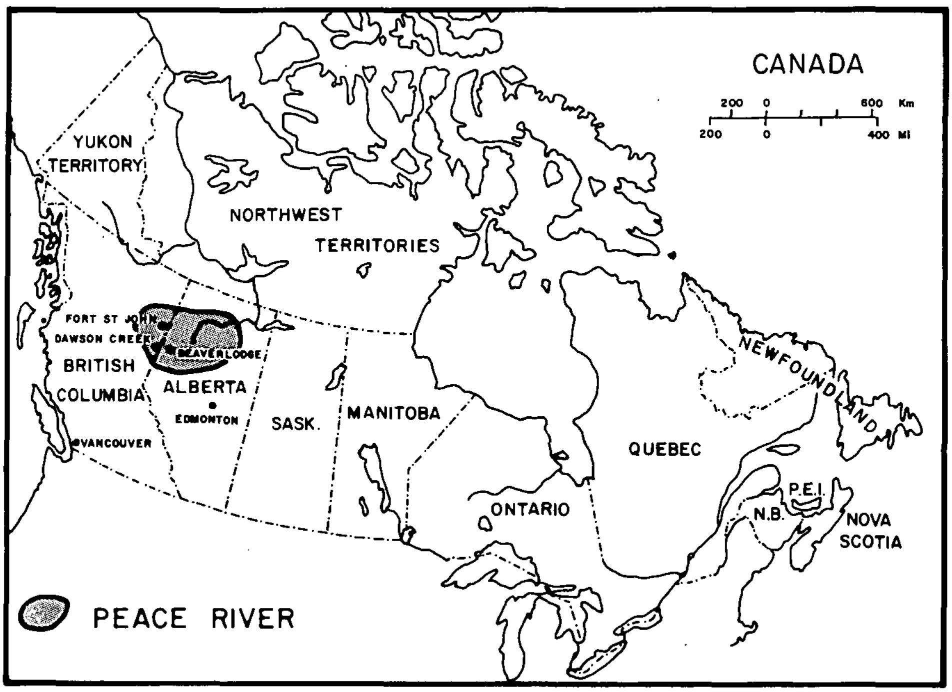

Figure 9.1 Location map.

a relatively long history of soil erosion problems (Albright, 1938; Johnson, 1961; van Vliet, 1979; Novak and van Vliet, 1983). A lack of soil erosion data for the area has hindered the development of effective erosion control and soil conservation planning.

In response to this need for a data base, the senior author initiated in 1979 a research project with the following objective: to determine the magnitude and extent of soil erosion by water (sheet and rill) on agricultural land in the Peace River Region. The approach taken consisted of two parts: plot studies from erosion monitoring and soil loss predictions. With measured soil loss data from runoff plots, the magnitude of soil erosion under different cropping systems can be determined, while at the same time these data are also useful for verifying soil loss predictions by the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978). The latter was used as a tool to map the extent of soil erosion for the region at a scale of 1: 100,000.

The application of this erosion information in map form is useful for two reasons:

1. To target erosion control and soil conservation funding in areas with high rates of erosion.
2. With a computer based data system, to evaluate the land for different land use and soil conservation scenarios. For example, to evaluate the impact of reducing crop land erosion by increasing the area in permanent pasture, or by growing more trees, or by increasing the use of soil conservation practices.

The first erosion plots were installed in 1979 at Beaverlodge Research Station (Figure 9.1) to measure soil loss under natural rainfall conditions for different cropping systems. Since 1982, 16 erosion plots have been operational at 3 locations in the Peace River Region.

This paper deals with results from the Beaverlodge erosion plots only, since it has more years of data compared to the other plot locations (Dawson Creek and Fort St. John).

Annual and seasonal measured soil and runoff losses will be discussed for the 3 cropping systems under investigation.

9.2 Description of the area

9.2.1 Location

The Peace River Region comprises part of the Peace River drainage basin, originating in the Rocky Mountains to the west and extending via British Columbia into Alberta. The area extends from north latitude 55° in the south to 58° in the north and from 115° west longitude in the east to 122° in the west. Elevation ranges from approximately 650-750 m above mean sea level.

9.2.2 Physiography and Soils

The area is part of the Interior Plains physiographic region, consisting of the Peace River lowland and the Alberta Plateau subdivisions (Bostock, 1970). The plains section consists of flat lying, Cretaceous shales and sandstones overlain by undulating and rolling till plains. The lowland area consists of lacustrine and alluvial deposits.

The main rivers have cut deep post-glacial channels, as much as 250 m deep, which in places expose the underlaying upper Cretaceous bedrock. The Peace River valley area is in places 3-5 km wide. The soils in the region are dominantly well drained and medium to fine textured, which have developed on glacial till, lacustrine, and fluvial materials. In decreasing areal extent, the soils are classified at the Great Group level of the Canadian System of Soil Classification (Clayton et al., 1977) as: Gray Luvisol, Solod, Solonetz (Black), and Dark Gray Chernozemic. The closest FAO/UNESCO equivalents are: Albic Luvisol and Podzoluvisol, Solidic Planosol, Mollic and Orthic Solonetz, and Greyzem respectively. The soils at the Beaverlodge plot location belong to the Dark Gray Solod Subgroup (FAO/UNESCO equivalent: Solodic Planosol).

9.2.3 Climate

The Peace River Region has a moderate, continental climate, dominated by Polar Continental and Arctic air masses. The summers are mild to warm, and the winters relatively cold. More than 50% of the total precipitation falls during the growing season, mostly as local thunderstorms of short duration and high intensity. The long summer days are mainly responsible for the relatively long hours of bright sunshine, averaging about 2,050 hours per year. During the winter, a warm dry Chinook wind may cause a rapid disappearance of snow with accompanying soil erosion problems.

Mean annual precipitation varies between 400-500 mm, of which about 40% (175 mm) falls as snow mainly during the months of November to April.

The mean daily temperature in January varies from –15° to –20°C, while the one for July varies from 14° to 18°C. The average freeze-free period varies from 60-100 days, although several locations have up to 125 days (Farley, 1979).

The growing season degree days (above 3°C) vary from 1,700-2,000 with an average length of 145-165 days. Average potential evapo-transpiration varies between 450-500 mm, carrying a climatic moisture index of 60-80% (Baier, 1976).

9.2.4 Agriculture

About 80% of the total Canadian area in farmland, in improved land, and in cropland, is found in the Prairie Provincies (Manitoba, Saskatchewan, Alberta, including the Peace River Region of British Columbia). The Peace River Region represents 5-7% of the total Prairie area in farmland, in improved land, and in cropland (Table 9.1).

Table 9.1 Present use of farmland based on 1981 census data 910^{6}ha).

	Peace River	Prairie Provinces[1]	Canada
Farmland	2.7	54.5	68.0
Improved Land	2.3	37.7	44.3
Cropland	1.6	24.6	31.0
Improved Pasture	0.2	2.9	4.4
Summer Fallow	0.5	9.5	9.7

[1] Manitoba, Saskatchewan and Alberta

The major crops grown in the Peace River Region are canola (rapeseed), barley, wheat, and tame hay and forage production (creeping red fescue, timothy, etc.). The agricultural production per unit area basis reflects a low intensity agriculture, but in total is an important one for the respective provincial and national economies.

9.3 Materials and methods

9.3.1 Plots

Standard Wischmeier plots (Wischmeier and Smith, 1978) were constructed at Agriculture Canada's Beaverlodge Research Station during 1979 (2 plots) and 1980 (4 plots). The plots are located on a uniform, 11% west facing slope. Plot dimensions are 22 m long and 4.5 m wide. Plot area is approximately 0.01 ha. Individual plots were separated from the adjacent land by vertical boards and berms to prevent external runoff from entering the plot area and at the same time preventing plot runoff from leaving the plot area before it could be measured and sampled.

9.3.2 Runoff Collection

Runoff from snowmelt or rain flows downslope and is diverted into a 30 cm wide flume. In the flume, a water level recorder provides a time record of water depth and duration of event. The flume directs the water into a Coshocton-type runoff sampler (Parsons, 1954) which turns and collects a 1% sample of the total flow. Water in the collection cans is measured for volume. For each plot, duplicated depth integrated half liter samples are taken for sediment and nutrient analyses from the collected runoff. More details on plot design, operation, and runoff collection are described by van Vliet (1983).

9.3.3 Cropping

Plots 1 and 2 were broken out of bromegrass-alfalfa sod on August 28, 1979, followed by plots 0, 3, 4, and 5 on August 8, 1980. Table 9.2 presents an overview of the 3 cropping systems for the plots.

Table 9.2 Cropping systems for beaverlodge erosion plots.

	Plot number					
Year	0	1	2	3	4	5
		REP 1			REP 2	
1980	–	Canola	Fallow	–	–	–
1981	Fescue	Barley	Fallow	Fescue	Canola	Fallow
1982	Fescue	Canola	Fallow	Fescue	Barley	Fallow
1983	Fescue	Barley	Fallow	Fescue	Canola	Fallow
1984	Fescue	Canola	Fallow	Fescue	Barley	Fallow

Continuous grass, continuous fallow, and an annual crop are replicated twice. At the same time, the annual crop represents a cross-over experiment between barley and canola to allow soil loss comparisons for both annual crops.

9.3.4 Precipitation

Meteorological measurements are made routinely at Beaverlodge Research Station. The site is 1 km from the plot location. Annual and mean precipitation data for each of the 5 years of erosion plot monitoring are presented as bargraphs in Figure 9.2, together with the 1951-1980 normals (Atmospheric Environment Service, 1982).

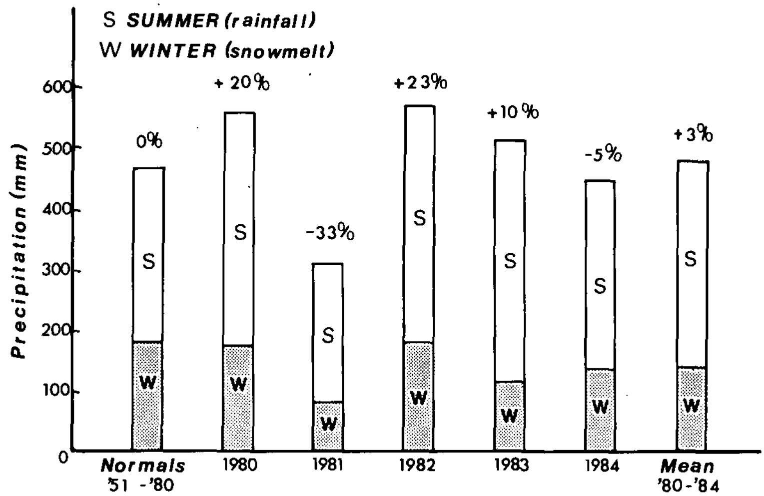

Figure 9.2 Normal, annual and seasonal precipitation at Beaverlodge, Alberta.

The annual deviation from the normal (1951-1980) precipitation is indicated as a percentage on top of each bar. To reflect seasonal precipitation values, normal, annual, and mean precipitation bars in Figure 9.2 are partitioned into summer precipitation from rainfall (S) and winter-spring precipitation from snowmelt (W). The precipitation data and percentage deviation from the normal values will aid the interpretation of the soil loss and runoff data in the results and discussion section.

9.4 Results and discussion

In this section, soil loss and runoff data for individual events (van Vliet, 1983) are combined into annual soil loss and runoff values for the 6 plots (Tables 9.3 and 9.4 respectively). Both tables are condensed into the bargraphs of Figures 9.3 and 9.4, representing annual and seasonal soil loss and runoff data for the 3 cropping systems. Each crop value is the mean of replicated plots, except for the 1980 data. The data in Figures 9.3 and 9.4 are summarized in Figure 9.5 as 1980-1984 mean values for the 3 cropping systems. Also, USLE predicted plot soil loss values are presented in Figure 9.5.

9.4.1 Soil Loss

Annual Soil loss data for the 6 Beaverlodge erosion plots are presented in Table 9.3.

The data in Table 9.3 show reasonably good agreement between replicated plots, with the exception of plots 1 and 4. Differences between the annual crops (plots 1 and 4) during 1981 and 1982 was caused by Coshocton wheel problems on plot 4, resulting in higher values than plot 1. Also note the lower soils loss values for plot 5 compared to plot 2 for 1981 and 1982, expressing clearly the stablizing and erosion reducing effects of the previous (plowed) sod by roots and grass residue. This favourable effect has disappeared in 1983. It is interesting to note the variability from year to year and for the different crops.

The continuous fallow plots have the highest soil loss values by one order of magnitude compared to the other plots (grass and annual crop). This is due to the absence of any vegetative cover or crop canopy to protect the soil from rainfall impact and runoff. The grassed plots (fescue) produced slightly higher soil loss values than the cropped plots, but soil loss values were much lower compared to the fallow plots. It will take several years before the fescue crop is well established with a complete crop canopy. Therefore, the amount of bare soil in between the fescue crop in 1981 and 1982 caused higher soil loss values than the cropped plots. This is also expressed in the average annual values of Figure 9.3. With fescue being established during 1983, this trend has reversed itself, as indicated by the data in Table 9.3.

The data of Table 9.3 are expressed as annual, seasonal, and 1980-1984 mean soil loss values for the 3 cropping systems in the bargraphs of Figure 9.3. Annual soil loss values were partitioned into soil loss due to rainfall representing summer conditions (S) and soil loss due to snowmelt representing winter-spring conditions (W). In order to facilitate seasonal comparisons between years, soil loss values from snowmelt (W) were expressed as an average percentage of the total annual soil loss values for the 3 cropping systems combined. This is shown in Figure 9.3 as a horizontal bar on top of the bargraphs for each year. The data in Figure 9.3 indicate that seasonal

Table 9.3 Annual soil loss data for Beaverlodge erosion plots (kg/ha).

		Plot number					
Year	# of Events	0 Fescue	1 Canola-Barley	2 Fallow	3 Fescue	4 Canola-Barley	5 Fallow
1980	3	–	418	2903	–	–	–
1981	9	3057	970	5979	3373	1618	3171
1982	8	405	691	40012	574	1326	30273
1983	10	23	101	8234	45	75	9116
1984	6	54	42	527	4	108	1007
Mean	(80-84)	885	444	11529	999	782	10892

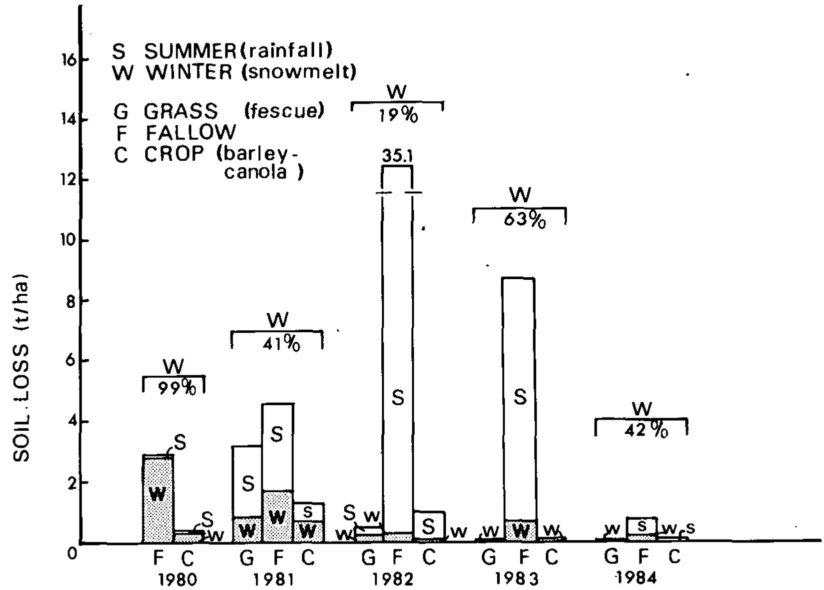

Figure 9.3 Annual and seasonal soil losses by crops for Beaverlodge erosion plots.

soil loss values are extremely variable from year to year. Soil loss from snowmelt expressed as a percentage of total annual soil loss (W) varied from 99% in 1980 to 19% in 1982 with a mean (1980-1984) of 53%. During 1980, only 1 runoff event in the summer produced negligible amounts of soil loss, hence the relatively high contributions (99%) from snowmelt. This pattern is completely reversed for 1982 due to a record rainfall event which dumped 94 mm in 21 hours with a maximum 30-minute intensity of 50 mm/hr. This one event produced on the fallow plots an average of 27,443 kg/ha, which accounted for 78% of the 1982 total annual soil loss. As a result, the contribution from snowmelt, masked by this large event, accounted for 19% of the annual soil loss. Figure 9.3 also shows that with the exception of 1980, the majority of soil loss on the fallow plots took place during summer rainfall events rather than during the snowmelt period.

Seasonal soil loss values are less variable between crops than between years. In 1983, no soil loss producing runoff events were recorded during the summer for the grass and cropped plots and no summer soil loss occurred on the grass plots in 1984. The same soil loss patterns between cropping systems and between years that were discussed for Table 9.3 are reflected in the bargraphs of Figure 9.3.

9.4.2 Runoff Volumes

Annual runoff data for the 6 Beaverlodge plots are presented in Table 9.4.

The data in Table 9.4 indicate fair agreement in runoff volumes between replicated plots. Just as with the soil loss values, differences in runoff volumes between plots 1 and 4 in 1981 and 1982 were caused by equipment failure on plot 4. Also, runoff volume on the fallow plot 5 in 1981 is much lower than on plot 2. This could be caused

Table 9.4 Annual Runoff Data for Beaverlodge Erosion Plots (kl/plot).

		Plot number					
Year	# of Events	0 Fescue	1 Canola-Barley	2 Fallow	3 Fescue	4 Canola-Barley	5 Fallow
1980	3	–	6.969	6.747	–	–	–
1981	9	6.863	15.507	15.401	4.563	8.874	5.174
1982	8	12.685	6.075	12.760	10.383	8.310	18.550
1983	10	5.016	3.349	6.616	6.679	2.356	8.907
1984	6	9.330	0.110	9.476	0.260	0.330	1.440
Mean	(80-84)	8.474	6.402	10.200	5.471	4.968	8.518

by first year continuous fallow after sod (plot 5) having a much higher infiltrability than second year summer fallow (plot 2). However, for no apparent reason, this pattern has reversed itself for the same plots during 1982. Table 9.4 also shows the variation in runoff from year to year and for the different crops. The summer fallow plots produced on an average (1980-1984) the higher amount of runoff, with the grassed and cropped plots producing on an average (1980-1984) lower amounts of runoff than the continuous fallow plots. Also, the runoff data show less variation from year to year and between crops compared to the soil loss data.

The runoff data in Table 9.4 are expressed as annual, seasonal, and 1980-1984 mean soil loss values for the 3 cropping systems in the bargraphs of Figure 9.4. Annual runoff volumes were partitioned into runoff due to rainfall (S) and runoff due to snowmelt (W). In order to facilitate seasonal comparisons between years, runoff caused by snowmelt (W) was expressed as an average percentage of the total annual runoff amount for the 3 cropping systems combined. This is shown in Figure 9.4 as a horizontal bar on top of the bargraphs for each year. The data in Figure 9.4 indicate less variation in seasonal runoff volumes compared to the soil loss data. For example, runoff from snowmelt expressed as a percentage of total annual runoff varied from 99% in 1980 to 62% in 1982, with a mean (1980-1984) of 70%. This clearly indicates that the majority of the annual runoff occurs as snowmelt during the winter-spring period.

It is interesting to note that no runoff was measured for the cropped plots during the summers of 1983 and 1984, although the rainfall amount during June and July 1983 was more than double the normal. The rainfall characteristics were quite different than is normally the case in that there were rainstorms of low intensity but long duration. All the rainfall had a chance to infiltrate into the soil since the barley and canola crop canopy on the plots had prevented the soil from sealing off by dissipating the kinetic energy of the raindrops.

When annual or seasonal runoff volumes and soil loss values in Figures 9.3 and 6.4 were compared with annual or seasonal precipitation values in Figure 9.2 there does not appear to be a clear pattern, except for the extreme event in July 1982 producing highest runoff and soil loss values. It seems that antecedent soil moisture, soil management, soil tilth, cropping management practices, and the nature of the rainfall and snowmelt are the variables that dominate the runoff and soil erosion processes, rather than just precipitation amounts.

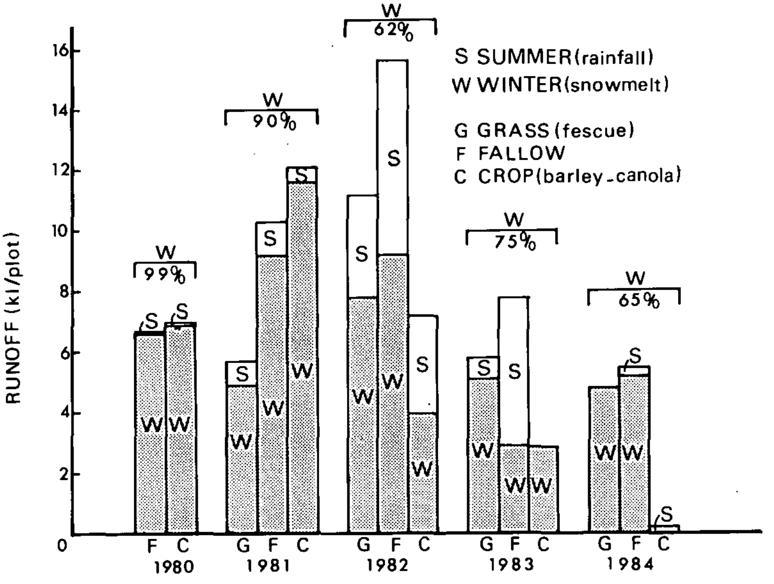

Figure 9.4 Annual and seasonal runoff volumes by crops for Beaverlodge erosion plots.

Figures 9.3 and 9.4 could be used for making all kinds of comparisons. For example, for the fallow plots, 11% of the annual runoff produced 62% of the annual soil loss during the summer of 1981, etc.

The data from Figures 9.3 and 9.4 are summarized in Figure 9.5 as 1980-1984 mean

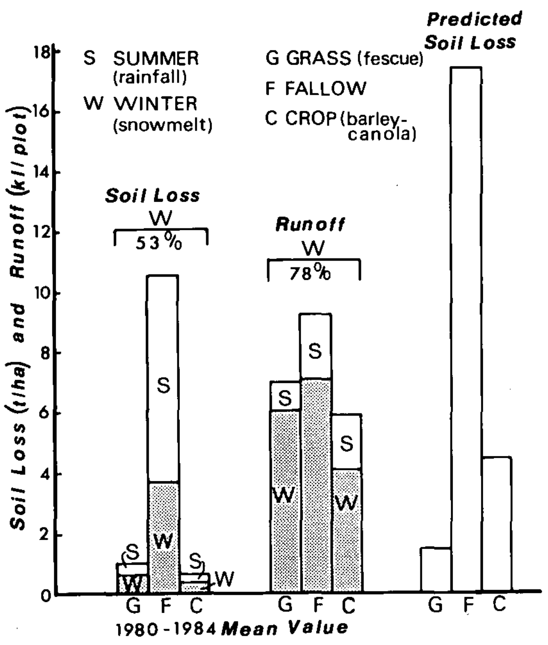

Figure 9.5 Summary.

values for the 3 cropping systems. Also, predicted (USLE) soil loss values are presented in Figure 9.5. A comparison of the data indicates that measured annual soil loss values agree with annual runoff values relative to the 3 cropping systems. For example, the higher runoff resulted in higher soil loss. However, this agreement does not hold for individual years, as was explained before. Also, 78% of the annual runoff volume caused 53% of the annual soil loss during the winter (snowmelt) period.

Predicted plot soil loss values (USLE) are higher compared to the 5-year mean measured soil loss values. One should realize that USLE soil loss values are longterm predictions based on at least 20 years of climatic data. The shortcomings of comparing longterm data with 5 years of measured soil loss data is apparent. This comparison also shows much higher predicted soil loss values for the annual cropped plots compared to the measured values. Possibly, the cropping management factor in the USLE should be better adjusted for Peace River Region conditions.

9.5 Conclusions

The main conclusions that can be drawn from 5 years of data for the Beaverlodge erosion plots are:

- Individual event and seasonal and annual measured soil loss values are highly variable over time and between cropping systems, while runoff volumes are less variable.
- One major localized thunderstorm accounted for over 70% of the 1982 annual soil loss on the continuous fallow and cropped plots.
- Continuous fallow plots have by far the highest soil loss values by one order of magnitude compared to the grassed and annual cropped plots.
- Just over 75% of the mean (1980-1984) annual runoff occurred during the spring snowmelt period, producing just over half of the mean (1980-1984) annual soil loss.
- Mean (1980-1984) annual soil loss values agree with mean (1980-1984) annual runoff volumes relative to the 3 cropping systems. However, this agreement does not hold for individual years.
- Plot measurements give great insight into erosional processes during different seasons of the year.

9.6 Acknowledgements

The following persons are acknowledged for plot maintenance and data collection for the Beaverlodge erosion plots: L. Kerr and B. Sterr. Runoff samples were analyzed by L. Chan. We gratefully acknowledge the financial assistance of an Agriculture Canada EMR grant.

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Discussion

Eppink: How do you account for snow-melt when predicting soil loss?
van Vliet: We have been using a snow-melt factor developed in the Peluse area and Washington State; the USDA guidelines are not entirely satisfactory; they consist of taking the total snow fallen during a certain period; say a month, and multiply it by 1.5, which factor is then added to the R-value in USLE; however this matter is receiving more attention after the problems around rainfall erosion have been solved.

Millington: Under USLE the prediction for crops was too high and you were going to investigate the cropping factors, but they were also high; are the differences not due to the physical parameters but rather the cropping factors; are you studying the soil loss under predicted fallow or actual fallow? *van Vliet:* We are more interested in the cropping factor than in the actual fallow; the various parameters will all be part of the evaluation that will be made of the applicability of the system.
Stromquist: The intensity of the snow-melt is more important than the deviation of snowfall and amount of snow, was this looked into?
van Vliet: Yes, true; very rapid snowmelt caused by the Chenook may have a dramatic effect; there are data available to study this process more intensely in the future.

Flach:
Do you have in the study area snow-melt on froozen soil?
van Vliet: Yes, we have; but also on basically saturated soil when a frost line occurs at 10-20 cm depth.

Flach: Are the plots to measure the soil losses of the appropriate size if we want to study erosion by rain and snowmelt over large areas; is the size of the 12 standard (small) plots not inhibitive to the results?
van Vliet: The studies were conducted on plot sizes recommended for the Wischmeyer equation; thereafter, a verification will follow in the field.

Driessen: What is the meaning of 'predictive' in the papers title, as the only thing that one can predict is the past, as there is little information available on rainfall and snow-melt?
van Vliet: USLE is looked at as a prediction equation, to predict erosion risk; two things must be separated:
1) mapping erosion risk at 1: 100,000 and on rational level at 1: 1 Milj. and
2) the need to look into effects of the past and present erosion; this may be done by looking at standard modal profiles and by assessing how much soil has been lost from the A-horizon for example in a certain amount of time; soil loss measurements are verified by soil conservation officers that have long experience and knowledge on the matter in this area.

10 The land quality: resistance to erosion and its application in the Iuni Catchment Area (Machakos District, Kenya).

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Summary

Along the lines of the FAO framework for land evaluation a new revision of the criteria and ratings used by Kenya Soil Survey for the land quality 'resistance to erosion' has been undertaken. A qualitative evaluation is made of slope angle, slope length, crop cover, soil and climate factors. These factors are rated individually on a scale where the lowest number normally taken as 1 is associated with a low risk of erosion and the highest number with a high risk of erosion. The ratings of the factors are then added up to give a total score which results in a classification of this land quality and can be used to identify areas of high, moderate and low resistance to erosion even before or after improvement.

The criteria and ratings of the land quality 'resistance to erosion' have been applied to the sample area – the Iuni Catchment, Machakos District. In the catchment, areas classified as being highly resistant to erosion are those which are covered by bare rocks and grass. Areas classified as being moderately resistant to erosion have slopes of less than 16% and slope length of 50-100 m. Areas which are of low resistance to erosion have steep slopes (16-30%) and often without conservation measures.

It is to be mentioned that the proposals of the criteria and ratings mentioned in this paper will have to be subjected to a more extensive program of testing before they can be generally applied.

10.1 Introduction

Data available in Kenya on erosion by water indicate that excessive quantities of top-soil have been washed from cultivated slopes and overgrazed pastureland (Ongweny, 1976 and Edwards, 1977). Due to increased population, it has become necessary to cultivate on steep slopes that are highly vulnerable to soil erosion. In the process of the physical evaluation of these soils for different land uses the quality resistance to erosion is very important and its evaluation will indicate the conservation practices required to reduce soil losses to acceptable values.

The land evaluation system as applied by the Kenya Soil Survey has been following the lines worked out in the earlier work of Beek and Bennema (1972) and the FAO Framework (1976). One of the important land qualities that is frequently considered is the 'resistance to erosion' by the Kenya Soil Survey. This has been done since 1973, but as a logical process subsequent revisions of the criteria have to be undertaken, as with time more basic data become available. The proposals worked out in this paper are the result of such an exercise. It is realized that for this land quality at a national level still many 'hard data' on erosivity and soil erodibility are lacking, with the consequence that in the evaluation only the semi-quantitative approach could be used up to now. As the functional application of the proposals is of major importance, the evaluation of this land quality according to these proposals has been executed for several soils in the country.

The criteria and ratings of the applied land evaluation procedure of the Kenya Soil Survey are subject to continuous testing and when proved to be necessary revisions are made. The land quality 'resistance to erosion' has been revised recently. Data resulting from erosion trials and erodibility measurements show that a more adequate dimension can be obtained for the assessment of this land quality. One of the aims of the Kenya Soil Survey is to involve characteristics which are easily available or which are measured within the standard range of field and laboratory procedures carried out during the soil surveys. The proposals mentioned in this paper will have to be subjected to a more extensive program of testing before they can be generally applied. The first phase of limited testing and the application to the Iuni area in the Machakos District is given as a specific example, as much work on erosion aspects has been carried out in this area by Thomas and Barber (1978).

10.2 Method – factors and ratings

The land quality 'resistance to erosion' after the last revision (Braun, van de Weg, 1977) was composed of the following land characteristics:
- climate
- slope class
- slope length
- soil erodibility.

During the recent revision it was felt necessary to consider plant cover as a separate characteristic, allowing the evaluator to include specific considerations related to the different land utilization types (LUT's). In this proposal the following factors of the land quality 'resistance to erosion' are considered:
- climate factor
- slope factor
- soil factor
- plant cover factor.

The rating of the land quality is obtained by a process of summation of the individual factor ratings and the final result can be expressed in terms of high, moderate, low and very low resistance to erosion.

10.2.1 Climate factor

According to Moore (1979) the rainfall erosivity in Kenya is strongly related to the kinetic energy of 15 minutes for rainfall intensities of over 25mm/hr. He calculates the relationship between this kinetic energy and the mean annual rainfall for the four zones in Kenya:

coastal region	$Y = 11.46\,x - 2226$	$r = 0.84$
inland lower than 1,250 m	$Y = 22.82\,x - 15795$	$r = 0.96$
inland higher than 1,250 m	$Y = 3.96\,x + 3122$	$r = 0.55$
Uganda plateau in which	$Y = 16.58\,x + 6963$	$r = 0.92$
	$Y = KE_{15} > 25$ (J/m^2/year)	
	x = mean annual rainfall (mm/year)	

The rating and the relation with the agro-climatic zones is the following:

rating	$KE_{15} > 25$	agro-climatic zone*
1	< 5,000	VI, VII
2	5,000–10,000	III, IV, V
3	> 10,000	I, II

The limit of 6,000 J/m^2/year as used by Moore, has been lowered to 5,000 J/m^2/year to include zone V – in which there are some agricultural development possibilities to the lower rainfall limit of 500 mm/year – in the same ratings group as zones III and IV.

10.2.2 Slope factor

The slope class and the slope length are combined in the slope factor. Because of the dominant influence of the slope angle over the slope length in erosion processes, the first characteristic has been given a heavier weight in the table of ratings. Whenever intermediate slope classes are used, their ratings can be obtained by interpolation (in around figures).

slope length (m)	slope class %	A 0-2	B 2-5	C 5-8	D 8-16	E 16-30	F 30-45	G >45
< 50		1	1	3	3	5	5	7
50-100		1	3	3	5	5	7	7
100-200		1	3	5	5	7	7	9
> 200		3	5	5	7	7	9	11

10.2.3 Soil factor

For the soil factor the characteristics included are specifically related with the surface horizon (0-20 cm) **. These characteristics are:
- organic matter
- bulk density
- silt/clay ratio
- flocculation index.

* Sombroek et al., 1982
** In a later stage also some sub-surface characteristics will have to be included.

The subratings for the mentioned characteristics are the following:

r_1: Organic mater.

	%OM	or.	%C
1	>5		>3.0
2	2–5		1.2–3.0
3	<2		<1.2

r_2: Bulk density (g/cm^3).

1	<1.20
2	1.20–1.50
3	>1.50

r_3: Silt/clay ratio (hydrometer method).

1	<0.20
2	0.20–0.59
3	0.60–1.00
4	>1.00

r_4: Flocculation index*

1	>70%
2	40–70
4	10–39
6	<10

The total soil factor rating is obtained by adding the subratings of the individual soil characteristics. The overall classification is as follows:

Soil factor rating		sum subratings ($r_1+r_2+r_3+r_4$)
1	high	<9
2	medium	10–14
3	low	>15

* flocculation index $= 100\,(1 - \frac{\%\text{ natural clay}}{\%\text{ total clay}})$, in which total clay is obtained by using a dispersing agent, for natural clay no dispersing agent is used in the determination.

10.2.4 Plant cover factor

The rated criterion for the plant cover factor is the average plant cover during the rainy seasons, expressed as percentage. The ratings are as follows:

rating	plant cover %
1	>70
2	50–70
4	20–49
7	<20

10.2.5 Final rating 'resistance to erosion'

The final rating is obtained by the summation of the subratings shown by the individual factors climate, slope, soil and plant cover. These final ratings can be classified as follows:

rating	sum factors
1	<10
2	11–15
3	16–20
4	>21

10.3 Case study: The Iuni Area

10.3.1 Climate

The mean annual rainfall for the Iuni Catchment as a whole is in the order of 900 mm (Thomas et al., 1981). The distribution of the rainfall is bimodal with one rainy season during March to May and the other during November and December. In terms of daily rainfall, for instance, it has been shown (Thomas et al., loc. cit.) that for the Nov-Dec 1978 rainfall, only 5 days out of 31 days with rain had falls greater than 20 mm which is considered as a low figure for the area.

10.3.2 Physiography

The study area, which forms part of the Iuni Catchment (Machakos District) ranges in elevation from 1,600 m to 2,000 m. The slopes are predominantly convex in shape with slopes ranging from 5% to 45%. The drainage is deeply incised. Three physiographic units are identified viz. hills, footslopes and river valleys. The hills have slopes of 30-40% but in some places increasing to more than 60% (mainly confined to the cliffs). The footslopes which have slopes ranging from 5% to 30% extend from the crest lines downslope to the break in slope, where the valley sides are of moderately steep slopes. The river valleys have slopes ranging from 2-5%.

10.3.3 Soils

The soils have developed mainly from the Basement System rocks consisting of granitoid gneisses, muscovite-biotite schists (Baker, 1954). These are generally well drained, moderately deep to deep, dark reddish brown to dark brown with sandy clay loam to sandy clay topsoils becoming gradually finer with depth. The soils are characterized by weak, subangular blocky structure with a strong tendency to form a surface sealing. Based on the data collected by Thomas and Barber (1978), the soils have low organic matter contents, low cation exchange capacity values and are deficient in phosphorus, nitrogen and calcium.

10.3.4 Vegetation and present land use

Most of the original trees have been cleared and replaced by Acacia species. The land is cultivated mostly with subsistence crops – maize, beans and pigeon peas. Land which is not used for cultivation is generally used for grazing cattle, sheep and goats.

10.3.5 Soil erosion and conservation

For a long time soil erosion has been a serious problem in Machakos District. Peberdy (1966) (quoted from Thomas et al., 1981) states that livestock was allowed to graze outside the district in 1911 and 1914 in an effort to alleviate overgrazing. A comparison of air photos taken in 1948 and 1972 in some parts of Iuni Catchment Showed that most of the gullies observable on the 1972 photograph were already present in 1948 (Thomas, 1974). Results from rainfall simulator trials at Iuni (Thomas and Barber, 1978) gives mean soil loss of 12 ton/ha from bare land on 12% slope with a storm of 69 mm/hr. During the time of the survey some visible signs of erosion – bareland, interrill, rill and gullies – were observed.

Most of the slopes in the study area require conservation measures. In Iuni, the main conservation measures consist of cut-off ditches and steep backslope terraces. The latter construction is known locally as the 'fanya juu' method (Thomas, 1979). In the study area, terracing has been carried out to an extent of almost eliminating soil loss from cultivated land.

10.4 Discussion

The climate criteria as applied is the best index of erosivity available in Kenya at the moment (Moore, 1979). Moore's map of rainfall erosivity in Kenya compares fairly well with the Agro-climatic Zone Map of Kenya (Sombroek et al., 1982). For this reason the climate factor ratings can be indicated with their distribution in terms of the agroclimatic zones. The slope factor reflects the influence of slope and relief on the detaching and transporting capacity of overland flow. For the slope factor it should be noted that the evaluation of the slope angle involves seven slope classes since land in Kenya is cultivated on slopes of 30-45% and of more than 45% as well (Thomas, 1979). The soil factor takes into consideration some important soil parameters which have a direct bearing on soil erosion. The organic matter content and the flocculation index are indicators for the aggregate stability, bulk density for generalized infiltration properties, and the silt/clay ratio for the susceptibility to sealing. These parameters have been used in several soil surveys of the KSS. Elsewhere in Kenya, these soil parameters have been known to correlate fairly well with soil loss (Gachene, 1982). As stated before, the plant cover factor is very important in the assessment of the resistance to erosion. The effects of specific land utilization types on the erosion can be expressed through this plant cover factor.

Special attention is given to the changes produced by conservation measures. In most cases it is possible to express these effects through the slope and/or plant cover factor, which factors can be catering for the relative effectiveness of these conservation measures, on the erosion. Nevertheless, in the overall process of land evaluation it will be necessary to consider the inputs and the benefits of the conservation measures in the economical analysis, as well as their effects on other land qualities other than the 'resistance to erosion'.

In Iuni Catchment areas classified as being highly resistant to erosion are those which are covered by bare rocks and grass. No more (or very little) soil can be eroded from the rocky areas and therefore soil erosion hazard is very slight from such areas. During the time of carrying out the fieldwork, areas which were under dominant grass cover showed very little signs of soil erosion (basal grass cover was found to exceed 80% even after long drought). While carrying out runoff plot trials at Iuni, Moore et al. (1979) found that even on a sloping area of more than 20%, grass basal cover of about 55% greatly reduced soil loss. Areas classified as being moderately resistant to erosion are characterized by slope per cent often less than 16 and slope length of 50-100 m, i.e. mainly with a slope factor of 3 and 5. Areas which are classified as being of low resistance to erosion are characterized by steep slopes (16-30%), long slopes (> 50 m) with a slope factor of 5 to 7), soils which are highly susceptible to erosion (soil factor of 5) and by lack of conservation measures. However, when conservation practices are taken into consideration most of the areas initially classified as being of low resistance to erosion are later classified as being of moderate resistance to erosion (the slope factor is reduced from 5 and/or 7 to 3). The effect the conservation measures have on soil erosion has been indicated in figure 10.1.

Although the above method of evaluating the land quality resistance to erosion tends to coincide fairly well with field observations and erosion testing, more data and research work are needed in order to bring the final picture more close to what would be expected to occur in the field. Thus the following requires further investigation:

- a qualitative evaluation should be made of slope shape, hence slope position. A detailed quantitative method carried out in Kenya (Gachene, 1982) showed the importance of slope shape and particularly position on the slope on erosion susceptibility. This suggests that in future, these two parameters should be included in the final rating of resistance to erosion;
- in some parts of Iuni Catchment(although not covered in this study) and also in some other places in Kenya, gravels do provide a permanent cover and hence the future erosion of such areas will depend very much on gravel cover. Thus the influence of this cover may lead to an increase in the resistance to erosion;
- of equal importance are areas which are subjected to flooding as a result of overland flow coming from adjacent steep sloping areas. Where such floods may negatively affect greatly the productivity of the land, this may lead to reduction in the resistance to erosion;
- in order to assess the accuracy of this qualitative method of evaluating the land quality 'resistance to erosion', the qualitative classification should be compared with quantitative parametric approach where the various factors (e.g. K-factor, R-factor, LS-factor, etc.) are quantified. However as much as this would be encouraged, very little data is available in Kenya on these factors. Thus more research on the individual parameters is required.

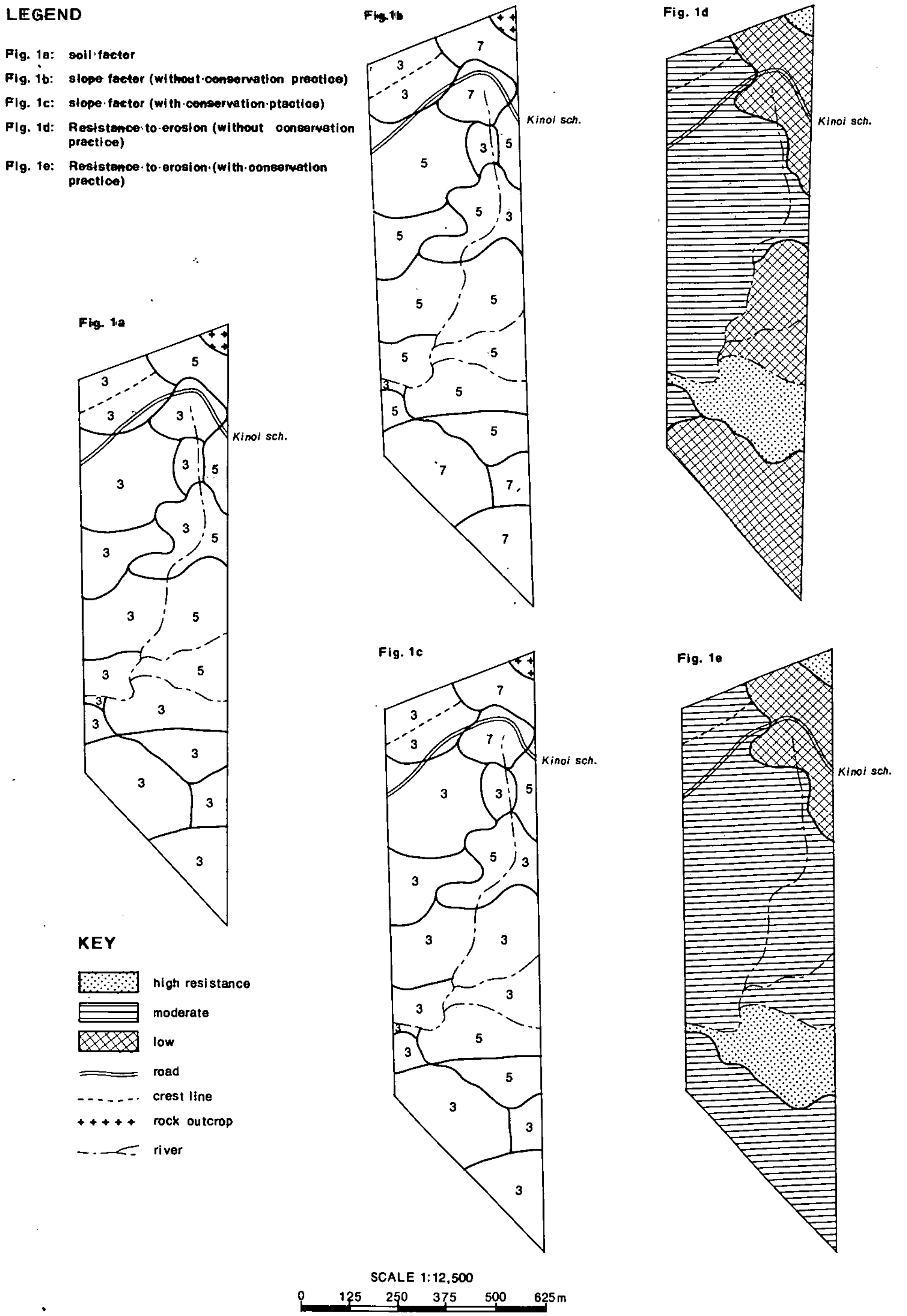

Figure 10.1 Rating of the land quality "resistance to erosion" in the Iuni sample area.

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11 Land inventory and traditional agro-technology information as basis for the mapping of land management units in Central Mexico

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Summary

The agriculture and economy of an area in eastern Central Mexico was studied. The traditional crop and land management practices of numerous cultivators were recorded within a framework of landscape units. Land systems and land facets were mapped. Then the value of the boundaries in explaining the variability of management practices and yield was checked by multivariate analysis of variance. Land facets that did not differ significantly in both management practices and yields were merged into units tentatively termed 'agrohabitats'. These are considered the starting point to further work on the definition of land management units.

11.1 Introduction

Land evaluation is based on the interpretation of physical land attributes with respect to specified kinds of land use, and the extent to which crop production can be achieved on a sustained basis, (i.e. without deteriorating the land resources), and their relevance in the economic and social context of the area concerned.

One of the purposes of land evaluation is to determine the best management and improvement measures for each alternative kind of land use.

However, land evaluation methods as currently used (FAO, 1984) are chiefly orientated towards the physical component of the evaluation giving little attention to man's activities on the land. Yet, it is management of land and crops which is largely responsible for the outcome from the production process and for the conditions in which the land is left at the end.

Management is the most dynamic aspect of the land-use system and therefore it plays a very important role in the improvement or degradation of the land. This is particularly true in sloping areas where agriculture may be practised under highly hazardous conditions.

Cultivators are aware of this. Under their own particular circumstances they have usually developed local measures to counter the negative effects of their activities on the land. These measures are incorporated into their traditional management practices. These management practices represent the cultivator's response to the environment. They are particularly suited to the characteristics of the landscape where the crop is being grown.

In this work crop and land management practices in a particular society in an area in Mexico have been studied. A land inventory of the area concerned was carried out first and the landscape units mapped into Land Systems and Land Facets. These units were used as a geographic framework to the study. The work aimed to check whether there was any association between management practices on the one hand, and the units of terrain on which they take place, on the other hand. As a direct consequence of the checking procedure some mapping units proved to be so similar in both management and yields that they could be merged. The new areal units, uniform in both their physical and management features, were tentatively termed AGROHABITATS. These agrohabitats may provide a useful basis for extension and management planning.

11.2 The background to this work

Effective measures to increase the productivity of the land and to promote land development require a thorough knowledge of the land resources, the varied ways in which they are being currently used, and a reliable assessment of what they are capable of producing so that predictions and recommendations can be made.

Adequate land resource surveys provide the basis for land evaluation and effective land-use planning. However the viability of any recommended land-use plan relies heavily on the extent to which it meets the circumstances and needs of the land users.

Thus, land must be evaluated in terms relevant not only to the physical and economic, but also to the social context of the area concerned (FAO, 1984).

Some current land evaluation methods give too little attention to the economic and social aspects. In most cases land surveys comprise the major source of the data on which the evaluation is based. On the other hand, detailed categorization of land utilization systems can be complicated indeed. Difficulties include the quantity and nature of the technical, social and economic data to be collected and the delimitation and matching of boundaries between land and land utilization systems. Temporal variability of their interactions adds another dimension to the problem.

Clearly there are two main components in any land-related activity. One is the land resource and the other is the land use itself. Hence, to evaluate the suitability of the land for a given use two main groups of data are essential:

a. the land resource data;
b. the land utilization data.

For the evaluation to be realistic the latter must be taken in its broader sense. It must comprise substantial information on the economic, social and cultural environments in which it occurs.

To determine the land characteristics and qualities, information must be drawn either from data already available or else from new surveys. Land resource surveys may be of two kinds: of individual land attributes or else integrated land surveys. Both aim to divide and classify the land on its various attributes. The former does it separately and its outcome are units of soil, climate, etc. The latter produces a single set of integrated units.

The merits of each type of survey have been discussed in numerous publications somewhere else (Christian and Stewart, 1968; Mitchell, 1973).

When introduced to an unknown area, on the other hand, we could also attempt to classify and divide the landscape not in terms of the physical attributes, but in terms of the land utilization. However, this may prove to be extremely complicated, for land utilization is more than just a choice of crop and crop-management variables but depends on social and economic factors too. Beek (1978) introduced the concept of land utilization type in attempting to deal with the systematization of land-use descriptions in terms of its technical and socio-economic interactions.

However, some problems in the matching procedure in land evaluation still remain solved unsatisfactorily. For instance, when comparing land characteristics and qualities against land-use requirements, by means of land units and land utilization types respectively, quite often there is a great discordance between land unit boundaries and the limits of land utilization types. A land unit may include more than one land utilization type and the other way round. The study of management practices, and how they relate to the land units in which they occur in a given land utilization type, provoked the realization of this work.

11.3 The land inventory

Due to their scope and nature, integrated surveys and notably the land system mapping (Beckett and Webster, 1965), had been found better fitted to meet the conditions and constraints inherent in the production of information and regional land-use planning in rural areas in Mexico (Leon, 1972). Recent work following this approach in that nation (Cuanalo et al., in press) has led to the completion of the country's Land Provinces and Land Regions survey, mapped at scale 1: 1M and based on satellite imagery and the available information. Land system and land facet surveys already exist for some areas within the country, and more work at this level of detail is being undertaken. This land classification system was preferred to soil survey for it is cheaper, quick, and provides integrated information in sufficient detail (i.e. Land Systems and Land Facets) to enable a straightforward assessment of the potentiality of the land for major land uses. Since it exploits intensively the merits of air-photo interpretation, it was found particularly suitable for areas of abrupt terrain, characteristic of the Mexican landscape. In such sloping areas the stereo-pair of photographs are quite an appropriate tool for separating units of land based on their physical attributes which are very evident. In those areas the investment in detailed or semi-detailed soil surveys could not have been justified.

Land Systems and Land Facets are the units in the classification hierarchy. They are conveniently mapped at scales between 1:250,000 to 1: 1M for the Land System, and between 1:10,000 to 1:80,000 for the Land Facet.

A Land Facet is part of a landscape which is reasonably homogeneous and fairly distinct from surrounding terrain. The Land System is a recurrent pattern of genetically linked Land Facets, and its description attempts to indicate their inter-relationships (Brink et al., 1966; Beckett and Webster, 1970).

An area of rough terrain in the region of Cuetzalan, in eastern Central Mexico, was surveyed (Figure 11.1), and land systems and facets mapped. The area selected can be said to be representative of sloping areas with abrupt and complex terrain and traditional subsistence agriculture. Two mapped land systems and their land facets

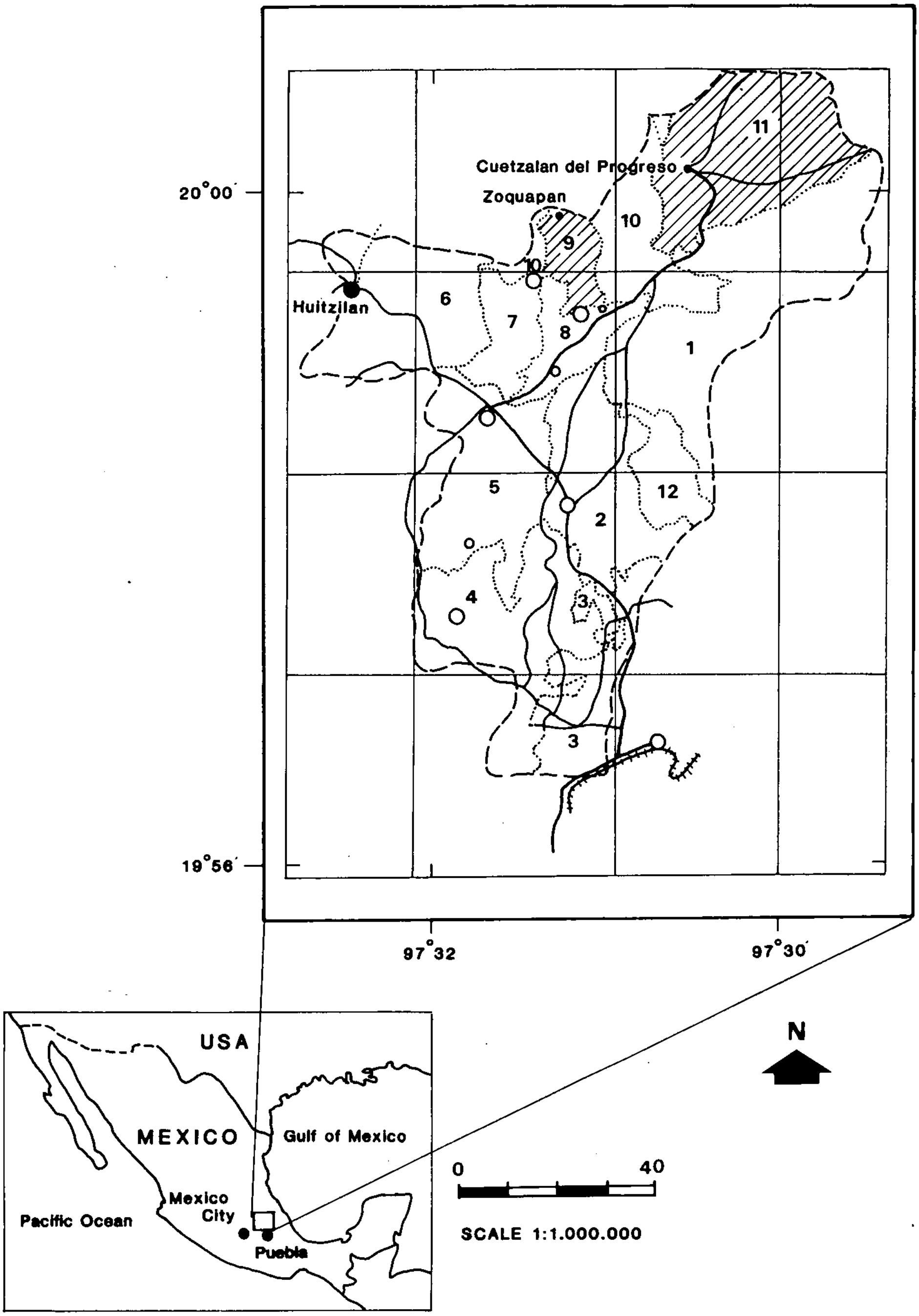

Figure 11.1 Location of the two Land System studied (dashed lines).

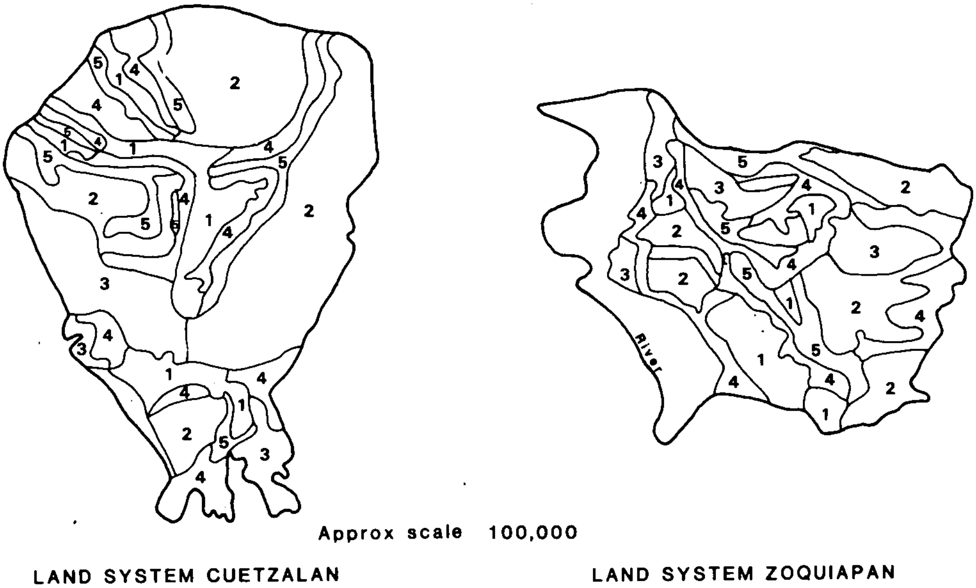

Figure 11.2 Land Facets mapped within the Land Systems considered for this study.

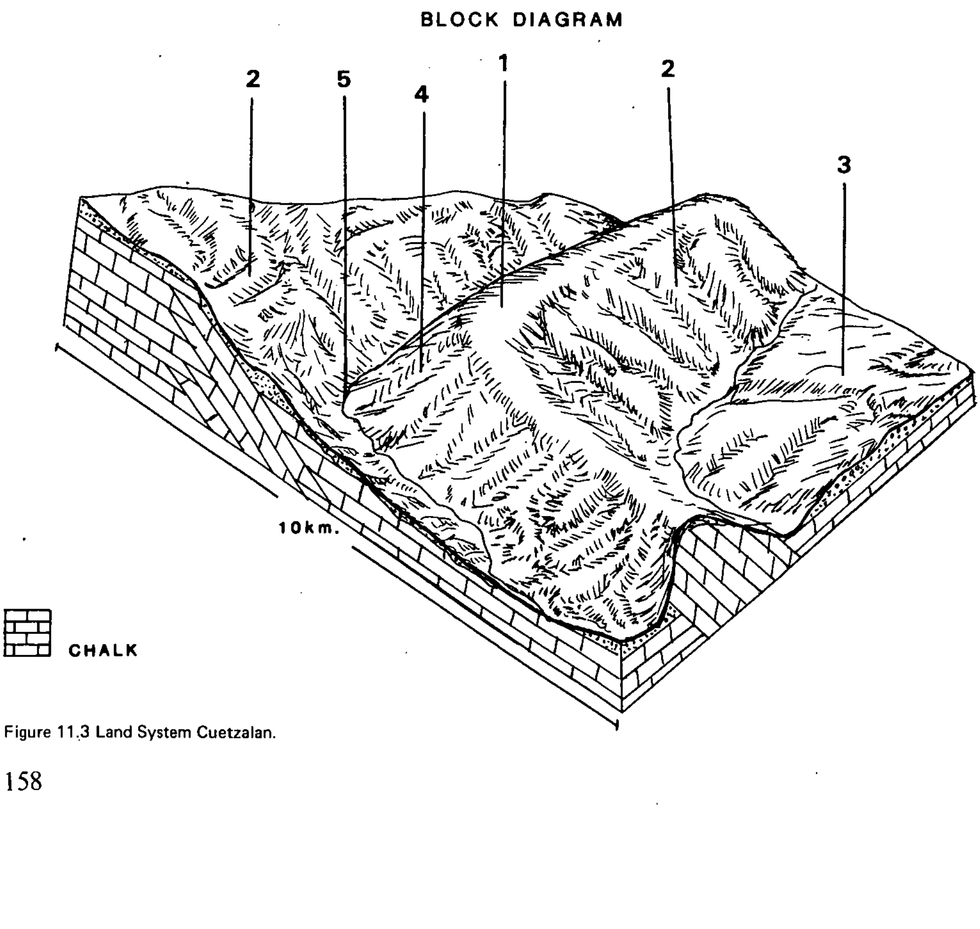

Figure 11.3 Land System Cuetzalan.

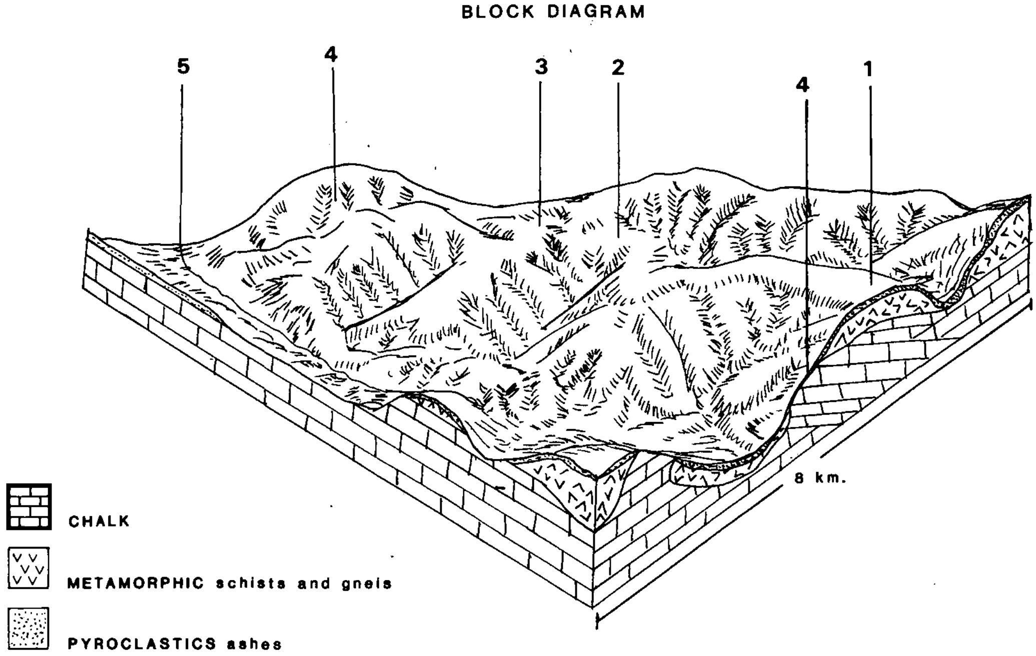

Figure 11.4 Land System Zoquiapan.

were distinguished; namely, Land System 'Cuetzalan' and Land System 'Zoquiapan', which bear local names (Figures 11.2, 11.3 and 11.4). Their corresponding land facets were fully described on their physical attributes (Tables 11.1 and 11.2). This comprised the first part of the data needed for this study.

Table 11.1 Information on the physical attributes of Land Facets from: LAND SYSTEM CUETZALAN.

Climate	Rainfall 1,800-2,500 mm; Annual Mean Temp. 18-27°C.
Rock	Early and Middle Cretacic calcareous rock (chalk), moderately weathered and fractured.
Landscape	Rock highly plaited and fractured, faults slides and fault-plains, descending scarps towards the long distant coastal plain.
Soil	Mainly deep (> 1 m) dark brown and reddish-brown clays, thinner on steep slopes and hill-tops, good organic matter content, moderately stony in places.
Vegetation	Low sub-perennifolious forest, sparse, grasslands, orchards and croplands.
Altitude	650-1,200 m.

Land Facet	Form	Soil, Materials and Hydrology	Land Cover
1	Crests of faulted blocks and plaits, with convex margins deepening to steep or moderate slopes.	Shallow (0-40 cm) clay and silty clays, stony (small stones) high in organic matter, dark brown and reddish-brown soils over highly fragmented chalk moderately weathered. Donating site, well drained.	Largely coffee, orchards, and some cultivated (Zea mays), (Phaseolus vulgaris).

2	Long anticlinal scarps of extended and moderate slope.	Deep (> 1.50m) lightly stony, silty clays and silty soils, rich in organic matter, brown and light brown, over chalk rock, well drained but with good moisture retention capacity. Intermediate sites.	Mainly grasslands alternating with cultivated Zea mays and beans (Phaseolus vulgaris). Few coffee orchards, and sparse sugar cane plantations.
3	Very small hills and light plaits, plains and lightly undulated lands.	Very deep (> 2.00 m), loams and clay loams, rich in organic matter, dark brown and brown soils over thin and localized alluvial deposits but largely over chalk rock. Well drained but high moisture retention capacity, normal and receiver sites.	Largely cultivated (Zea mays) and beans (Phaseolus vulgaris) and grasslands, few sugar cane plantations and coffee orchards.
4	Steep slopes and scarps of slides, faults and fractures.	Shallow (40-50 cm) fine textures, predominantly clay, highly stony, occasional chalk outcrops. High in organic matter, brown and reddish-brown soils, very well drained but not excessively. Donating Sites.	Mainly coffee orchards alternated with cultivated plots (Zea mays and Phaseolus vulgaris).
5	Flooding plains and stream flow basins in low small valleys parallel along	Very deep (> 2.00 m) mixed fine and rough textures. Silty clay loams and sandy clay loams, very stony in some places. Abundant organic matter and alluvions. Dark gray and brown alluvial soils. High flooding risk, excess of moisture and some water-logging particularly during rainy season. Receiver sites.	Almost all cultivated (Zea mays and Phaseolus vulgaris). Some sugar cane plots.

Table 11.2 Information on the physical attributes of Land Facets from: LAND SYSTEM ZOQUIAPAN.

Climate	Rainfall 1,600-2,000 mm; Annual Mean Temp. 15-27°C Rainy season in the summer but winter rainfall 5-10.2% of the total.
Rock	Early and Middle Cretacic calcareous rock (chalk), some places show incipient local metamorphism (schists and gneiss). In some localized places, later depositions of pyroclastics and ignimbrites over weathered chalk.
Landscape	Plaits of chalk highly fractured and faulted, fault-plains and small basins filled with pyroclastics, long descending fault scarps following the general slope towards lowlands and distant coastal plain.
Soil	Moderately deep (around 1 m) but in some places shallow, loams and silty or clay loams, dark or light brown hues.
Vegetation	Low sub-perennifolious and perennifolious forests, sparse, orchards, grasslands and croplands.
Altitude	800-1,400 m.

Land Facet	Form	Soils, Materials and Hydrology	Land Cover
1	Crests of faulted blocks and plaits, hilltops, with convex margins towards scarps and slopes.	Predominantly silts and loams, not very deep (0-40 cm), highly stony (small stones) and high to moderate organic matter content, dark grey to dark brown. Donating sites.	Largely forest, some coffee plantations and orchards.

2	Long scarps and extended moderate slopes.	Loams and clay loams, deep (> 1 m) dark and light brown, few stones, good organic matter content. Highly moisture retentive, but well drained. Intermediate sites.	Largely cultivated (Zea mays and Phaseolus vulgaris). Some grasslands and orchards and coffee plantations.
3	Foot plains, small hills of smooth slope, lightly undulated lands.	Deep (> 1.20 m) loams and clay loams and silt loams with good organic matter content, few stones, over mixtures of chalk and metamorphics or chalk and pyroclastics. Well drained, good moisture retention capacity. Receiver sites.	Cultivated (Zea mays and Phaseolus vulgaris) and some grasslands.
4	Steep slopes and fault-planes, steep scarps of faulted blocks.	Shallow (> 40 cm) clay and clay loams very stony (small stones) chiefly over chalk and occasionally over schists. Dark brown, well drained. Donating sites.	Cultivated (Zea mays and Phaseolus vulgaris) in proportion to grasslands and few forests.
5	Flood plains aside run-offs and small streams, basins and alluvial sediments.	Very deep (> 1.50 m) clays and clay loams alternating with silty loams and sandy loams. Alluvial deposits, dark grey or dark brown. Eminently receiver sites, occasional water logging.	Largely cultivated (Zea mays and Phaseolus vulgaris) some woodlands and grasslands.

11.4 This study

Clearly, the practical utility of the land units produced by any land inventory depends very much on the extent to which the land mapping units correspond to viable combinations of the land and crop management variables involved in a land utilization type.

This study aims to check to what extent a particular land facet is found to be associated with a particular and finite set of combinations of management variables and crops.

To this end the agriculture and economy of the region of Cuetzalan in eastern Central Mexico was described. The agriculture practiced there is traditional and possesses characteristics inherent to the agriculture practiced in a large portion of the country and in some other developing countries also. It is subsistence agriculture with low levels of input, very limited capital availability, and low yields.

Land systems and land facets served as a sampling framework for a survey of land and crop management practices. The survey was planned to obtain information on the dominant land utilization type. This was identified and provisionally defined during a pre-survey reconnaissance and turned out to be eminently agricultural. Using the terminology of FAO (1984) it comprises: 'Maize alone or row-intercropped with beans, for subsistence, very low capital intensity, high labour intensity level, following traditional methods, almost entirely human labour, little or no animal power, no mechanized farming, farming by traditional tools and harvesting by hand or machete, very small farms (< 1 ha), family or state owned land, also cash-rent and share-crop tenancies, permanent cultivation system (cultivation factor R = 85% to 90%), low inputs, organic manures and some use of chemical fertilizers (30-40%, local formula (10-8-4), generally low yields'.

Preliminary investigation also showed that the number of variables necessary to sufficiently describe all the main features of crop and land management was 37 and these were recorded and used in this study (Table 11.3).

Table 11.3 Variable components of the traditional crop management technology as distinguished from field survey records.

No.	Description	Symbol	Codification	Units
1	Cropping system: maize alone	M1	Area planted	% out of total arable owned
2	Cropping system: maize, beans (climbing beans)	M2	Area planted	% out of total arable owned
3	Cropping system: maize, beans (shrub beans)	M3	Area planted	% out of total arable owned
4	Fallow	PT	Times over before planting	No. of times
5	Date of fallow	PT1	Days from beginning of year	Day
6	Tools for rotaration	PT2	Use frequency of 'Azadon'	%
7	Tools for rotaration	PT3	Use frequency of plough	%
8	Planting	S1	Plant and number of replantings	No. of times
9	Planting data	S2	Days from the beginning of the year	Day
10	Tools for planting	S3	Use frequency of 'Espeque'	%
11	Tools for planting	S4	Use Frequency of 'Cuzo'	%
12	Distance between planted rows	DS	Estimated average distance	cm
13	Distance between plants	DM	Average estimated distance	cm
14	Grains of maize per plant bunch	G	No. of seeds	No. of seeds (average)
15	Grains of bean per plant bunch	G1	No. of seeds (average)	No. of seeds
16	Variety	V	0, 1, 2, 3 categories	Digits
17	Origin of planted seeds	V3	Portion from last harvest	%
18	Origin of planted seeds	V4	Portion bought	%
19	Manure as input	E1	Since last crop	Kg/Ha
20	Manure as input	E2	This season	Kg/Ha
21	Chemical fertilizer	N3	Quantity of nitrogen	Kg/Ha
22	Nitrogen fertilization date	N4	Days after planting	Day
23	Chemical fertilizer as input	P3	Quantity of phosphate	Kg/Ha
24	Phosphate fertilization	P4	Days after planting	Day
25	No. of cultivations	L1	Cultivations before top-cutting	No.
26	Tools for cultivations	L2	Portion of the area cultivated with plough	%
27	Tools for cultivations	L3	Portion of the area cultivated with 'Azado'	%
28	Date of first cultivation	L4	Days after planting	Day
29	Date of second cultivation	L5	Days after planting	Day
30	Date of third cultivation	L6	Days after planting	Day
31	Date of harvest	C	Days after planting	Day
32	Date of top-cutting ('Despunte' or 'Desmiahuatl')	DH	Days after planting	Day
33	Date of plant-bending ('Doblar')	D	Days after planting	Day
34	Usage of some weeds (as food-stuff)	AR1	Portion used as food out of total used	%
35	Use of some weeds (as forage)	AR2	Portion used as forage out of total used	%
36	Use of some weeds (as green coverage)	AR3	Portion used as coverage out of total used	%
37	Use of weeds (as material for structures)	AR4	Portion out of the total used	%

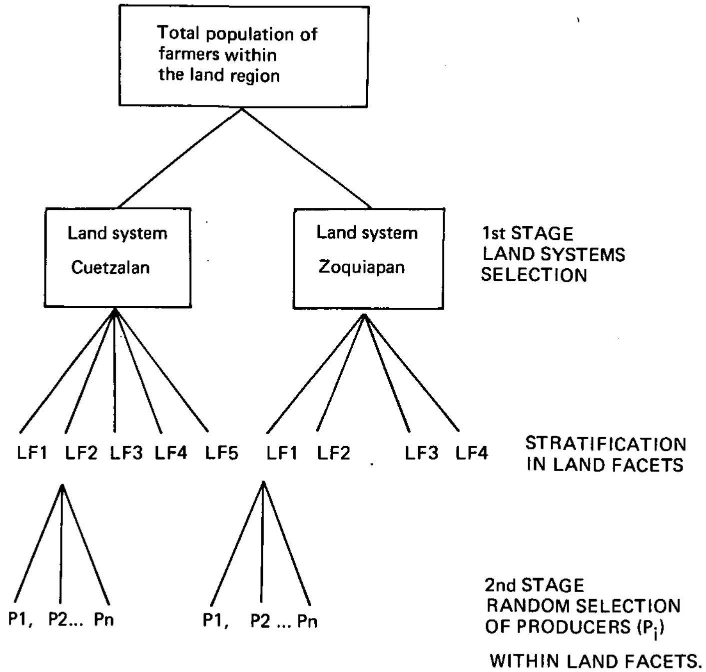

Figure 11.5 Sampling strategy for surveying land-use and crop management practices components of the local traditional agrotechnology.

The 37 management variables for each of the cultivators were recorded on fill-in questionnaires during one year spent living and working with them. Ninety (90) cultivators were carefully observed, interviewed and their practices recorded. Also recorded were their estimates of yields which were checked at post-harvest time and the estimates corrected when necessary. From these 90 cultivators randomly sampled, 40 were drawn from land System Zoquiapan and 50 from Land System Cuetzalan following a sampling strategy in two stages (Figure 11.5).

11.5 Data analysis

A data matrix of 37 x 90 constituted the information on management, and the second part of the data needed for this study. The two sets of data, on the land and on the management and yields, now had to be compared to see how far the land units and management were associated.

As a first stage, graphic displays of the schedules of management practices and histograms for some of the variables were produced. Examination showed that some of the data were redundant. Principal component analysis (Kendall, 1975) was carried out to reduce this redundancy in the data. The original 37 management variables were reduced to the first 15 principal components, which were selected according to the amount of information they described as given by their eigenvalues. It was not possible to associate the principal components with particular aspects of management. They may be thought of as 'compound scores of management' in this study.

The eigenvectors provided information as to which of the original variables contributed most to the variation described by each principal component. It was possible to recognize those variables that were responsible for most of the differences in management between cultivators.

The overall variability of these 15 principal components within land systems and facets was measured in terms of L or Wilk's Criterion (Webster, 1971) which is a multi-dimensional measure of the proportion of the total variance not accounted for by the land classes (i.e. land systems and facets). It is computed as a ratio of the determinants of the two matrices: H = sums of squares due to classes, and E = sums of squares of the error,

$$L = \frac{E}{H+E}$$

The significance of L was tested by transforming it to a form distributed as an F statistic (Anderson, 1958). This allowed joint analysis of variance of the 15 principal components. Thus, given values of Wilk's criterion $L_{p,n}$ then

$$\frac{1-L_{p,n}}{L_{p,n}} \cdot \frac{n+1-p}{p} \backsim F^{p}_{n+1-p,\alpha}$$

Where p is the number of dependent variables (i.e. 15 principal components) and n is the total number of sets of observations (i.e. of 90 cultivators). Subsequently values of Wilk's criterion (L) were submitted to multivariate analysis of variance. A hierarchical model was used to accommodate the nested effects of land facets within land systems. For the univariate case this could be represented by the model:

$$Ci,h,j,k = \mu + Sj + Fk(j) + Oh(j,k) + Ei(j,k,h)$$

Where C would be the value of the ith of the 15 principal components from the hth of the 90 observations, Sj is the variability of C due to the jth land system, Fk(j) is the variability of C due to the kth land facet within the jth land system, and so on.

Oh(j,k) would be the variability due to observations within the kth land facet within the jth land system. E is a measure of the residual error.

For the multivariate case, as in this work, the same model is expressed in terms of matrices (Morrison, 1967):

$$C = A\mu + e$$

Where C is the vector of 15 principal components, A is the design matrix, made up by the hierarchic or nested effects, μ is the matrix of parameters and e is the error matrix.

The variance of crop yields was also analyzed separately in its relation to land systems and land facets, using a hierarchical model similar to the one above. This analysis of variance was carried out jointly for both crops, i.e. maize and beans, and then individually for each crop.

More detailed analyses were performed to discover which land facets showed non-significant differences in both bean yields and management as represented by the 15 principal components. Land facets were compared with respect to these two sets of variables in pairs. They were subsequently grouped into units tentatively termed agrohabitats. These groupings may be regarded as the agronomic response to broad topographic contrasts. The groupings or agrohabitats were then mapped by deleting the original land facet boundaries when necessary and enclosing the grouped facets within a common boundary.

11.6 Results

On the graphic presentation of schedules and histograms the length of a bar indicates the overall range of variability among cultivators for each activity. On comparing this information between Land Systems (i.e. Figure 11.6 vs. Figure 11.7) they revealed some coarse differences in crop management practices. The activities in both land systems show comparable intervals, but in general those on Land System Zoquiapan show an overall lag of approximately 15 days for all the practices. This can be explained by the gross differences in terrain (e.g. altitude, exposure, microclimate, etc.) between the land systems. The figures also show that some management practices present in one Land System are missing in the other, for example, the variable DH (i.e. cutting of plant tops). In general the histograms suggest that data from Land System Cuetzalan has more structure (i.e. is more unimodal) than the data from Zoquiapan (Fig. 11.8).

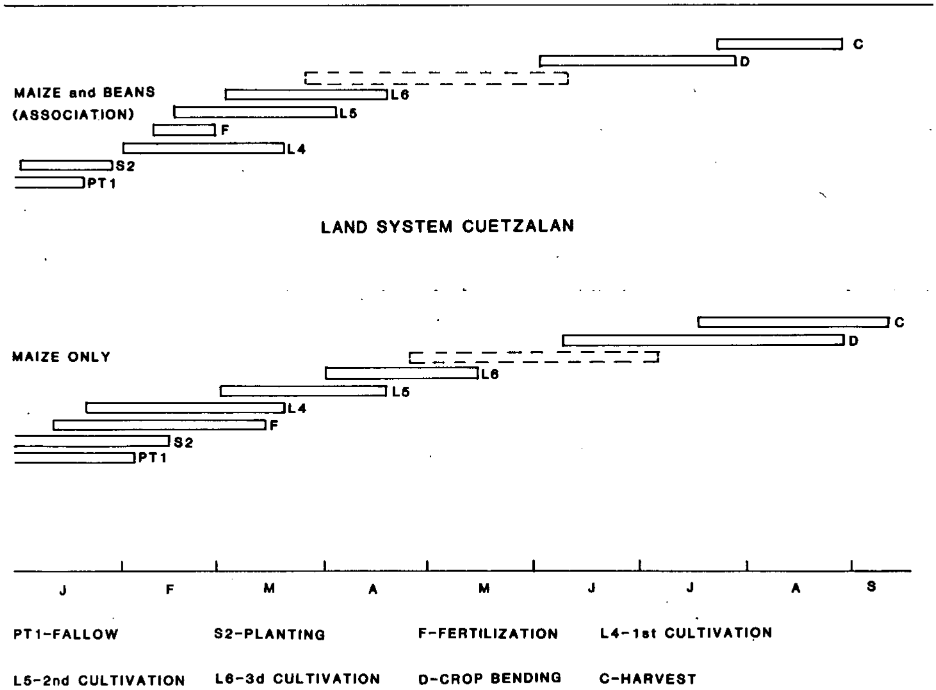

Figure 11.6 Crop management schedules.

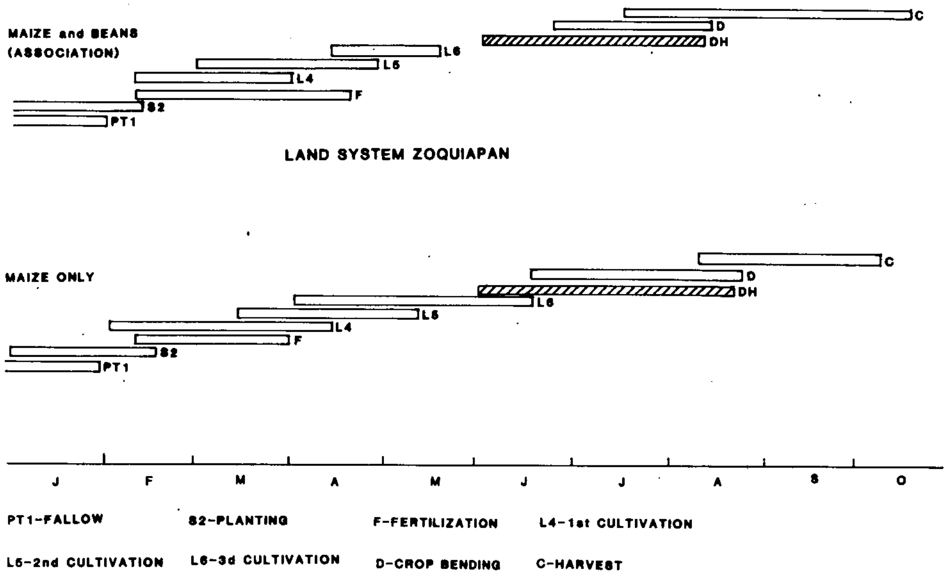

Figure 11.7 Crop management schedules.

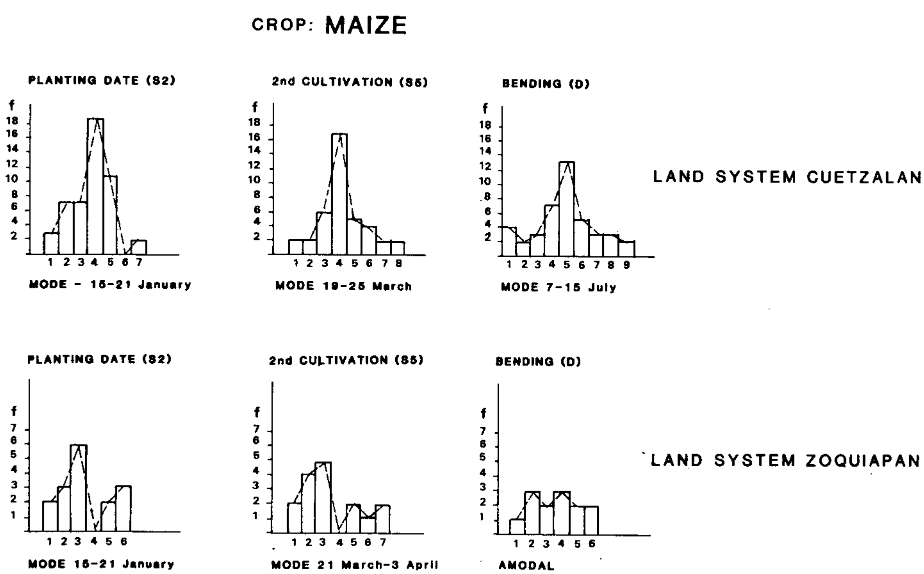

Figure 11.8 Histograms for some management variables stratified by Land Systems.

The eigenvalues and the individual and cumulative variation that they explain are given in Table 11.4. It can be seen that the first 15 principal components describe 83.2% of the total information. They were considered to provide an adequate number of variables for subsequent analysis. The first five principal components explain 45% of the total information.

The eigenvectors indicated the variables relevant to differences in management among cultivators. Variables such as M1, PT1, V4, AR2, and AR3 showed the highest absolute eigenvector values in the first five principal components. This means that cultivators differ most on whether to plant maize alone (M1) or intercropped, and decisions concerning the data of fallow (PT1), the variety of seed planted (V4), as well as on the post-harvest treatment of the land and weeds (AR2, AR3) accounted for much of the remaining disagreements among cultivators.

Table 11.4 Eigenvalues, % of the total variation explained by each, and cumulative variation of the first twenty principal components used as compound management variables.

Principal Component	Eigen values	% Variation	% Cumulative
1	5.0975	13.777	13.777
2	3.6516	9.869	23.696
3	2.7867	7.531	31.178
4	2.6002	7.027	38.205
5	2.5455	6.879	45.085
6	1.9645	5.309	50.395
7	1.8702	5.054	55.450
8	1.8261	4.935	60.385
9	1.5357	4.150	64.536
10	1.4482	3.914	68.450
11	1.3134	3.552	72.002
12	1.2372	3.343	75.346
13	1.1086	2.996	78.343
14	1.0584	2.860	81.203
15	0.9704	2.622	83.226
16	0.8467	2.288	86.114
17	0.7976	2.153	88.268
18	0.6446	1.742	90.010
19	0.6066	1.639	91.650
20	0.5864	1.584	93.235

Table 11.5 shows the results of the multivariate analysis of variance for the 15 principal components with land systems (S) and the facets within them (F(s)) as nested sources of variation. It can be seen from these results that land systems and land facets were found to be highly significant in partitioning the variability of the 15 principal components that represented the range of management practices. Clearly, in the area of this study there exists some degree of association between the delineations of land systems and land facets and traditional crop management.

Under a uniform physical environment crop yield differences are a direct response to differences in management. Thus, in order to check whether the variability in crop yields had some degree of association with land units, the results of a similar analysis of variance on crop yields are given in Tables 11.6 and 11.7. These results show that the maize yields are highly significantly associated with land systems but no significant

Table 11.5 Analysis of the joint variance of 15 principal components (used as compound management variables) between land systems, and between land facets within land systems.

Source of variation	Wilk's criterion: L value	F	Probability of error Type 1 (α)
S	0.32068719	F(15,58) = 8.190	0.0001**
F(S)	0.09824387	F(90,332) = 1.89	0.0001**

** Highly significant
S = Land System
F(S) = Land Facet within Land System

Table 11.6 Nested analysis of variance of bean yields against land units.

Source of variation	D.F.	S.S.	M.S.	F. calc.	Prob. F
S	1	2.032×10^4	2.032×10^4	29.76	0.0001**
F(S)	6	1.101×10^4	1.835×10^5	2.69	0.0207
Error	72	4.9170×10^4	6.8291×10^2		
Total corrected	79	8.0505×10^4			

** Highly significant
S = Land System
F(S) = Land Facet within Land System

Table 11.7 Nested analysis of variance of maize yields against land units.

Source of variation	D.F.	S.S.	M.S.	Calc.F.	Prob.F.
S	1	9.1479×10^6	9.14×10^6	9.53	0.002**
F(S)	6	6.6177×10^6	1.102×10^6	1.15	0.343 N.S.
Error	72	69.136×10^6	9.602×10^5		
Total corrected	79	84.901×10^6			

** Highly significant
N.S. Not significant
S = Land System
F(S) = Land Facet within Land System

differences were found between yields on the facets within those land systems.

As there were significant differences in bean yields between some land facets, further and more detailed analyses were carried out to discover which land facets in particular had significantly different bean yields.

The facets were statistically compared on their mean yields one against another by pairs. All plausible pairs were compared. The results are compiled in Table 11.8. From these comparisons it can be seen that for instance in the Land System Cuetzalan, land facet No. 2 was found to show yields significantly different from the rest of the facets in that land system. On the other hand, in Land System Zoquiapan, bean yields on Facets 2 and 3 were significantly different from those in Facets 4 and 5 which by and large showed no significant differences.

Table 11.8 Tests of significance of differences in bean yields between all pairs of Land Facets for each Land System.

Land system	Land Facets compared	Calc. F	Probability of error Type 1
Cuetzalan	1,2	2.66	0.120**
Cuetzalan	1;3	0.48	0.496 N.S.
Cuetzalan	1,4	0.08	0.780 N.S.
Cuetzalan	1,5	1.00	0.330 N.S.
Cuetzalan	2,3	0.23	0.635 N.S.
Cuetzalan	2,4	1.95	0.150**
Cuetzalan	2,5	4.45	0.049**
Cuetzalan	3,4	0.28	0.601 N.S.
Cuetzalan	3,5	1.00	0.330 N.S.
Cuetzalan	4,5	1.00	0.330 N.S.
Zoquiapan	2,3	0.85	0.360 N.S.
Zoquiapan	2,4	2.51	0.134**
Zoquiapan	2,5	2.86	0.108**
Zoquiapan	3,4	5.01	0.038**
Zoquiapan	3,5	8.13	0.010***
Zoquiapan	4,5	0.11	0.745 N.S.

** Significant at 85% of probability
*** Highly significant (probability of 99%)
N.S. Not significant

This indicated some degree of consistency in the results obtained. These results also began to point towards possible groupings of facets on the basis of their differences in bean yields.

At this stage the results of the multivariate analyses of variance had shown that there were significant differences in management variables between land facets within land systems. More detailed analyses were also carried out to find out on which of these land facets management was significantly different than in others. This was achieved by testing the statistic significance of the differences in management on one facet against another, in the same way as for bean yields.

Putting together the results of these tests with those for bean yields it was possible to go even further. It was clear that some land facets did not show significant differences in both crop yields and management. These facets must have had some degree of concordance in topography or some other kind of uniformity, presumably in crop growth limiting factors, such that cultivators under similar management produced comparable yields. This indicated that it was not unreasonable to assume that, for the purpose of crop production, they represented similar conditions, in the sense that a given crop can produce comparable yields if it is submitted to similar management and if grown where the environmental factors relevant to its growth and production are comparable. The significance of differences in both crop management and crop yields were then taken as criteria by which to compare landscape units (Table 11.9). Within each land system, land facets showing no significant differences in both of these two criteria were merged. New maps of the facet groupings were produced by deleting, where necessary, the boundaries between land facets that were to be merged and keeping the boundary common to two groups of facets.

Table 11.9 Criteria for the grouping of Facets in Agrohabitats.

Facets compared	Differences in crop management	Differences in bean yields (85% P)
	LAND SYSTEM CUETZALAN	
1 vs 2	Not significant	Significant
1 vs 3	Not significant	Not significant
1 vs 4	Not significant	Not significant
1 vs 5	Not significant	Not significant
2 vs 3	Significant	Not significant
2 vs 4	Not significant	Significant
2 vs 5	Not significant	Highly significant
3 vs 4	Not significant	Not significant
4 vs 5	Not significant	Not significant
4 vs 5	Not significant	Not significant
	LAND SYSTEM ZOQUIAPAN	
2 vs 3	Not significant	Not significant
2 vs 4	Not significant	Significant
2 vs 5	Not significant	Significant
3 vs 4	Not significant	Highly significant
3 vs 5	Not significant	Highly significant
4 vs 5	Not significant	Not significant

The new areas on the maps have been termed agrohabitats. They are presumed to have some degree of uniformity in the crop's limiting factors at very local level. These maps of agrohabitats are shown in Figures 11.9 and 11.10.

However, agrohabitats defined in this way are no more than working hypotheses subject to correction and modification as more information is obtained from crop behaviour, yields and management over a period.

Given the sparse evidence and the coarseness of the data, it may be too adventurous to suggest that units like agrohabitats may be amenable to mapping. They are defined here as a starting point or working model to further work in the definition of management units for planning and advisory extension. Work elsewhere in Mexico (e.g. Pena, 1972; Zuleta, 1975; Aguirre, 1977) under similar conditions but using more abundant data from experimental plots, presents results going in the same direction.

If anything, the results show that land units and land crop management on them are amenable to checks by procedures like those used here or perhaps even by more refinement. Further, they show that there is a degree of association between the crop management practices locally chosen, and the land units on which the crop is being grown; i.e. that the cultivator responds to changes in landscape by adapting his management practices. This hints that planners should adopt a similar attitude and assign the recommended management to suit the changes in the landscape. It also suggests that for the purpose of defining areas for uniform management improvements and conservation practices during planning, landscape units and their related local management may serve as starting point.

The degree of the landscape-management-yields association was very clear from informal conversations with the cultivators while sharing their work in the fields. Unfortunately, subtle information like this could not be recorded at the coarse level of information inherent in the 37 variables of management recorded for this study.

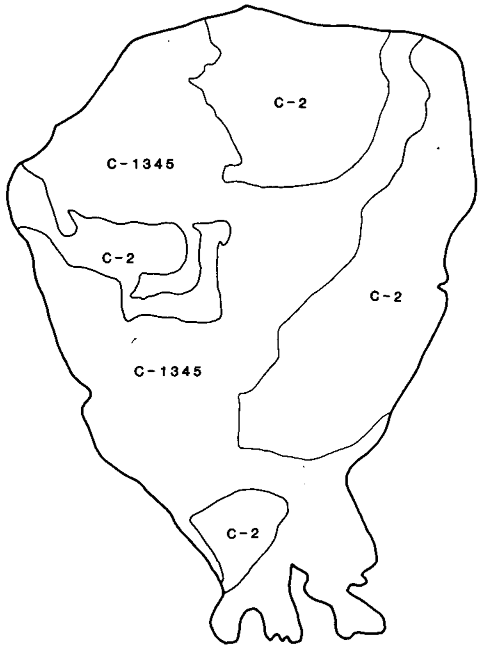

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Figure 11.9 Agrohabitats L.ST. Cuetzalan.

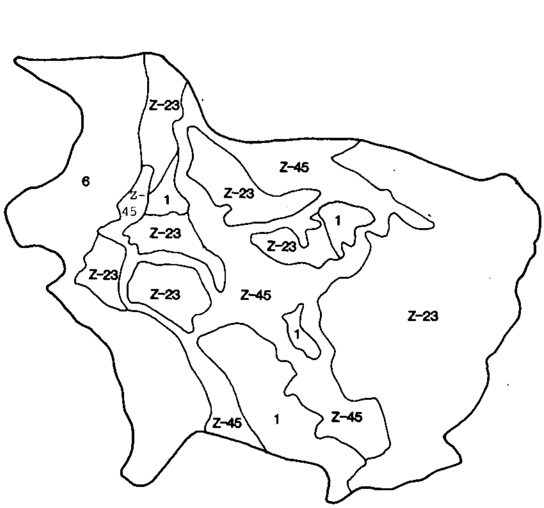

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Figure 11.10 Agrohabitats L.ST. Zoquiapan.

11.7 Conclusions

1. The analysis of variance showed that the boundaries of land systems and land facets did indeed divide the total landscape into land units that possessed substantial uniformity in 15 principal components from a set of 37 management variables.
2. This work, though not conclusive, showed that the utility of the landscape units as a basis for land planning may be checked against the traditional management practices taking place on them.
3. A good deal of the information gathered escaped any type of graphic or analytical treatment. Such information, obtained while sharing work and food with the producers, confirmed the rationality of those cultivators in their choice of inputs and management practices suited to the conditions imposed by the landscape.

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Discussion

Jungerius: Can anything be said about the quality of the data used in central Mexico; as it was found that during a similar study in Morocco that these were not very reliable ('noisy') and the farmer was kind of reluctant to part with information!
P-Hernandez: Yes, this is true; a way was found by using the local teacher to let the farmers believe that the interviewer was part of the teaching team and as such could be trusted; also the yields were checked in the field assessing the number of sacks and by weighing some of them to get an idea about kg/grain per bag.

Elbersen: Are soil surveys too expensive and can they only be paid or made payable when they are carried out for example on behalf of an irrigation scheme? In Mexico the same methodology is followed as at ITC but a different terminology is used; for small scale soil maps the physiographic approach is used combining the soil-landscape and the soil profiles; thus the smaller the map scale the more the influence of the landscape in soil mapping.
P-Hernandez: In Mexico the soil mapping is carried out at scale 1: 500,000 according to the FAO guidelines; instead of the planned 5 years already 10 have been used and only 35% of the country has been mapped, therefore another approach was needed.

McCormack: The paper illustrates explicitly the erosion problem in a farming community.

12 A spatial assemblage model for the estimation of gross erosion and sediment yield using remote sensing and geo-data-base operations

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12.1 Introduction

In an attempt to set up and operate a Geo-Information System (GIS) for erosion and sediment yield studies as a part of land evaluation procedures, the following considerations were made:

- Make optimal use of the surveying techniques using remote sensing imagery and aerial photo interpretation. For the quantification (i.e. transformation) of data contained in mapping units and of data pertaining to climate, vegetation, etc., make use of existing, common methods. Accept empirical methods when necessary (regional rates, extrapolation of field data, soil physical contants, results of regression).
- Make optimal use of existing simulation models for the assessment of the transformations.
- The approaches should be applicable to various scales.
- Accept region-specific elements (climate, relief, soils, land use, developments).
- Use a common data base for all land evaluation procedures and keep the geodata base adjusted to other requirements.
- Overruling of automated results should be possible at the various stages.

Considering all the intricacies of the erosional and sediment transport processes, one wonders whether it is worthwhile to attempt to use an assemblage of various methods at different levels of sophistication for the prediction of erosion and sediment yields. However, the success of hydrological models for not too small catchments, the availability of satellite data and the computer facilities to handle distributed data are stimulants in continuing the approach described here.

We are not yet in a position to evaluate the results. The work done so far has rather exposed weaknesses in components of the assemblage. Earlier such defuncts were known, but conveniently overlooked. Now, at least we know where to direct our research and development efforts in trying to build a reasonably trustable, semi-automated methodology.

The approaches are being tested in three different but sloping areas:

1. NW Argentina, including Andes ranges;
2. Central Highlands of Sri Lanka;
3. Kasserine area, Tunisia.

12.2 Main outline of the assemblage

The chart of Figure 12.1 gives the main procedures leading to a map with gross erosion rates and a map with estimated sediment yields. There are three more or less independent types of input:
- climatic data;
- vegetation and land-use data;
- physiographic and geomorphological data.

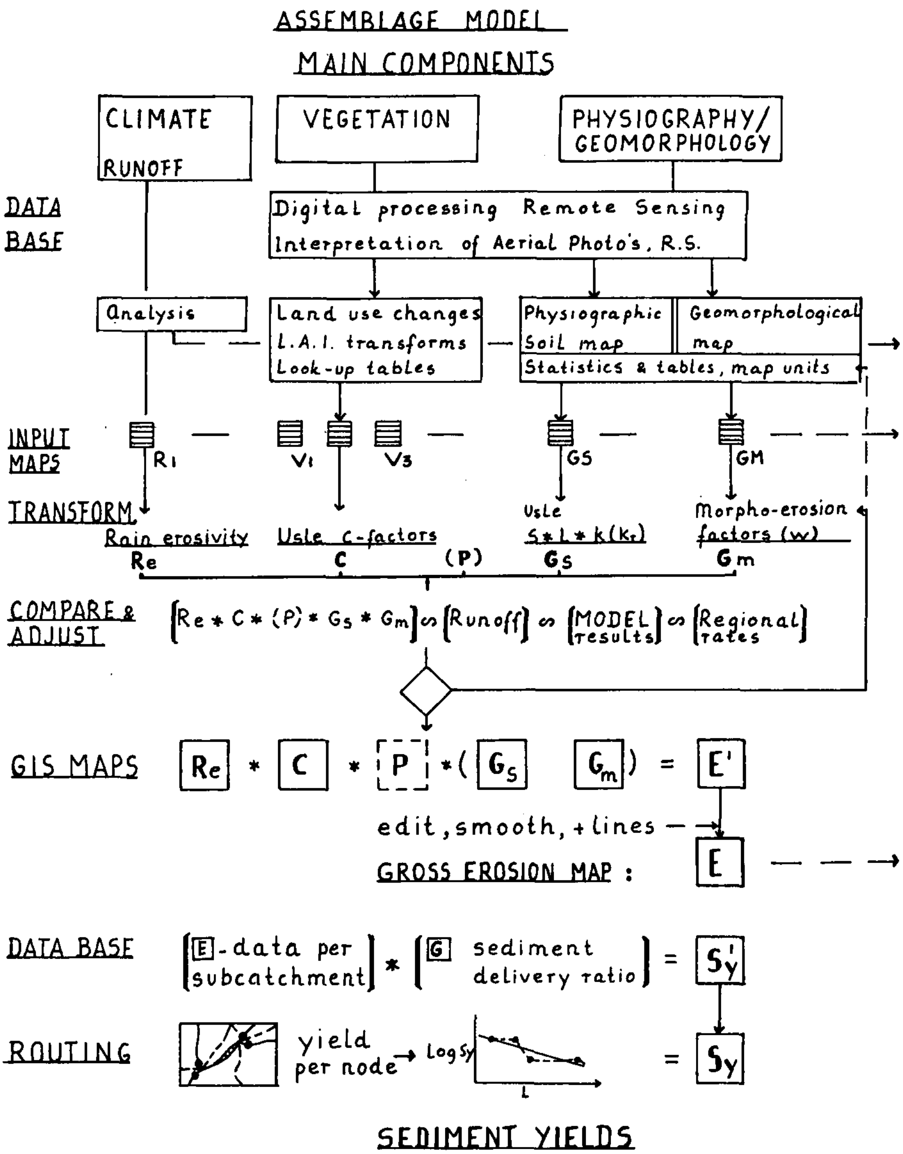


Figure 12.1 Erosion & sediment yield.

12.2.1 Data base

First a data base has to be compiled containing the basic raw data and treated data, as is illustrated in the charts below. Important components are thematic maps such as a physiographic map, a soil map, a geomorphological map or their combinations made in the conventional way. The maps are stored in the data base after digitalization (GIS). The vegetation-land use map may often consist of Leaf Area Index (LAI) transforms made from Landsat, with additional digitized land-use interpretations from aerial photographs or other sources.

12.2.2 Transformations

The rainfall data, prepared in the data base, will be transformed into a rainfall Erosion Index (EI) for the production of the gross erosion map. For other procedures in the land evaluation different maps will be produced, as is indicated in the charts of Figures 12.1-12.4.

Station values are plotted and with interpolation procedures, considering possible orographic effects, EI isolines are generated, digitized and converted to raster (pixels of the same size as resampled Landsat). The result is called the (Re) map in the GIS.

The vegetation map has to be transformed into a map showing the cover (C) factor of the USLE approach, or another index if so desired. This may be done by using two Landsat tapes, one for the dry period and one for the wet season. After LAI or NMI transforms a look-up table with C-values is made. The physiographic and geomorphological information is split up into tables which show the soil (K) and slope (L.S) factors of USLE per mapping unit and tables containing weighting constants (W) for areas under gullying, landslides, eroding channel networks. In mountainous terrain, an amalgamation of the physiographic and geomorphological data may be useful.

12.2.3 Comparison

Before the tables containing the (C) factors and the soil and geomorphological data are applied to generate GIS maps, trials are made for selected parts of the studied area (usually the best known or most important parts).

At this stage model simulations should be made, using the data prepared in the data base (not the GIS). So far, we have used the ANSWER model of Beasley et al. (Purdue) and Morgan's et al. (Silsoe) model. These model results are compared with those of the multiplied tables, with field observations and regional or known local erosion rates. The comparison will usually lead to an adjustment of the contents of the tables.

12.2.4 Gis maps

A sheet and rill erosion map (Gs) and a morpho-erosion map (Gm) can now be generat-

Map 1 Map Showing erosion classes in kg/ha resulting from GIS operation based on Morgan's model. Black and white reproduction of a colour map; dark units low erosion, light toned units higher erosion. Kandy area, Sri Lanka.

ed and the contents added, whereafter multiplication follows with the rainfall erosivity map (Re) and the cover factor (C) map, according to the USLE algorithm, yielding the E1 map.

Our experience shows that this map needs editing:

- overlooked errors, erosion classification of parts where no erosion occurs such as towns, depositional areas, etc.;
- smoothing operations for better presentation.

Map 1 shows the erosion map resulting from GIS operations using Morgan's model (black and white reproduction from original colour screen)

12.2.5 Sediment yield

The map showing the gross erosion (E map) is a basic document for the estimation procedures of the sediment yield. Boundaries of subcatchments and channel networks are digitized and the statistics concerning the gross erosion are asked from the GIS. Similarly, information from the Gs + Gm maps is derived and sediment delivery ratios per unit from the data base are applied to the subcatchments on a weighted area basis.

These results are presented in the form of sediment yields per subcatchment to the major river network. A simple graphical procedure – as yet – is used for routing the amounts downstream, taking into consideration link lengths of channels where floodplain deposition occurs and where incision takes place. It is the intention to replace the graphical procedure by a proper routing model.

12.3 Remarks concerning the components

12.3.1 Climate

Most operations in the data base, illustrated in Figure 12.2, can be performed using well-known methods. The following problems were met during the application of the procedures in our test areas:

- The intensity-frequency-duration data of point rainfall is difficult to obtain. One may have to resort to empirical ratios of short to long duration rainfall. The runoff and erosion models often require short-term rainstorm input. To find an 'average standard storm' in the various seasons is no easy matter. Perhaps use of probability density functions of daily rainfall may be helpful.
- In other erosion models monthly or yearly runoff is required. We find a big gap between the Thornthwaite and Mather water balance methods and the physical model (such as SWATRE of Feddes et al., ILRI, for example) which require formidable input. We are trying out the results of the former method, using 10-day periods.
- The determination of the EI_{30} index is a major effort, for which basic data may be lacking anyhow. In the Andes test area an empirical adjustment of the Fournier index was used, but the correction is based on a station in the foothills. In Sri Lanka the value for one station, as estimated by Joshua, was used and variations within the area had to be estimated, introducing error. In the Tunisian area, a semi-arid region, one has the nagging doubt that the EI index may not be useful at all, because most of the erosion seems to occur during events of heavy rainfall with long recurrence intervals. Runoff data, if available for at least some small catchments, should be used fully, as indicated on the chart of Figure 12.2. The derived values of the input parameters after calibration are helpful in estimating those parameters in other areas. We find that, in absence of runoff data, peak runoff rates as determined by the slope area method (Manning's formula applied to channels) give reasonable results, if grouped and averaged per geomorphological unit.

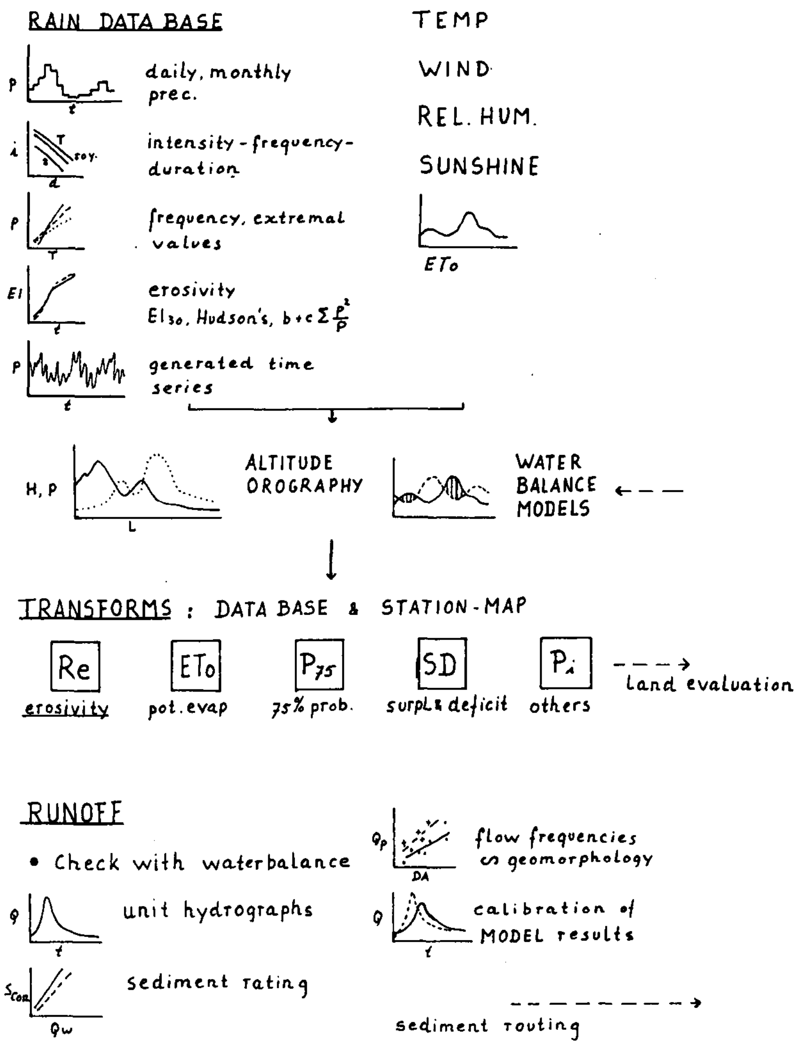


Figure 12.2 Climate.

12.4 Vegetation and land use

The remote sensing image processing is grouped under this heading because optimal benefit is made of the Landsat imagery for estimating the cover factor and for the assessment of the changes which may have taken place in the area (Figure 12.3).

It is generally not possible to derive sufficient information with regard to practice factors and even type of land use from the satellite data. Aerial photo interpretation and fieldwork is required, but the imagery may serve as a base map. Various techniques are possible to produce the best base maps. In hilly areas an intensity transform may provide a sort of relief map, essential for location, and filtered images using high-pass

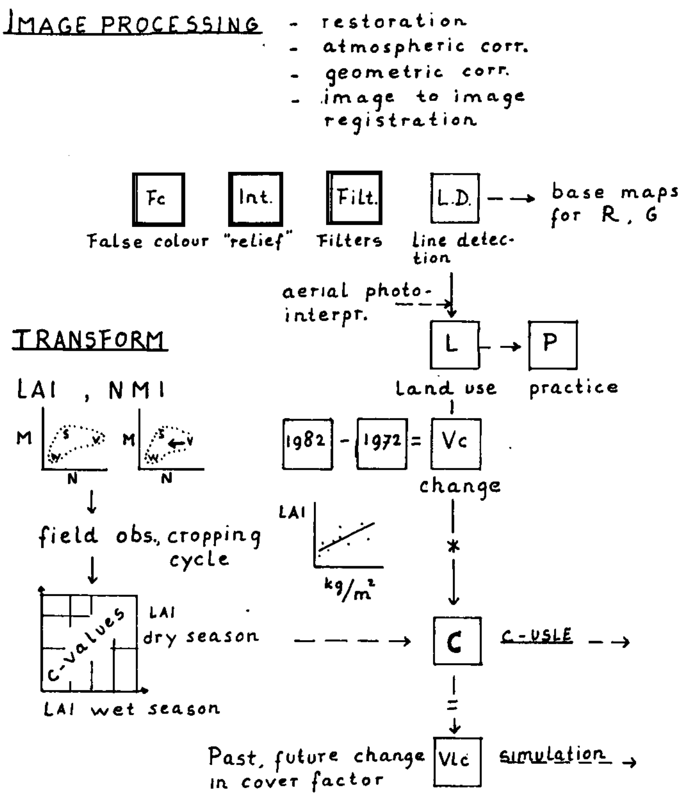


Figure 12.3 Vegetation — land use.

filters may enhance the drainage networks while in some regions line elements (roads, field boundaries, etc.) may be enchanced by other filters. The land use and practice maps are often compiled by plotting various parts of the region on different imagery.

It is commonly accepted that LAI transforms (b7-b5/b7α5) or the physically more acceptable NMI transform, are associated with vegetation densities in the field. In a general sense this is true for the test areas, but only up to a point. In Tunisia, for example, the correlation was not very satisfactory for open and dense forest stands. In the Sri Lankan area it was difficult to separate certain tea lands from paddy lands and some grasslands on the LAI image, but the corresponding (C) factors, as estimated in the field, are quite different.

In the Argentina test area large-sized fields in certain parts change to small parcelling in adjoining ones. From the small parcels mixed spectral signatures are registered. Different from the large parcels, but the ultimate cover factor may not differ very much in the large and small fields. For natural vegetation there seems to be no abundance of data in a form useful for relating the real densities in the field with the transforms of Landsat.

In our studies, LAI transforms were used and the (C) values in the look-up table, composed of the wet season and dry season scenes, were based on identifying known locations and estimates of (C), based on field knowledge. Because the (C) factor is of great importance in the estimation of erosion, much more research effort should be directed to the application of remote sensing in this domain.

Map 2 illustrates the difference of the LAI in the dry season and the wet season in the Argentine area.

12.5 Physiography and geomorphology

To avoid semantic difficulties: with physiographic units here is meant essentially genetical units which are subdivided on the basis of relief forms which have typical soil associations, usually in the form of catenas. Sheet and rill erosion are related to the physiographic units. The geomorphological units here are also genetical units (fluvial,

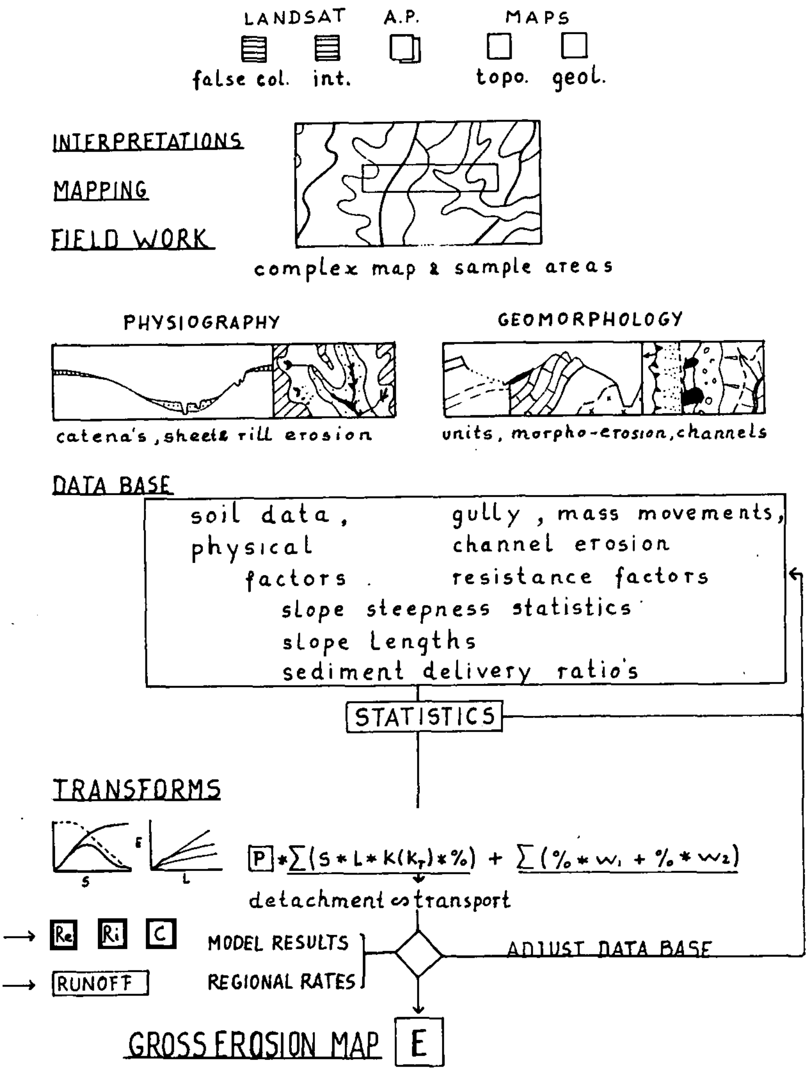
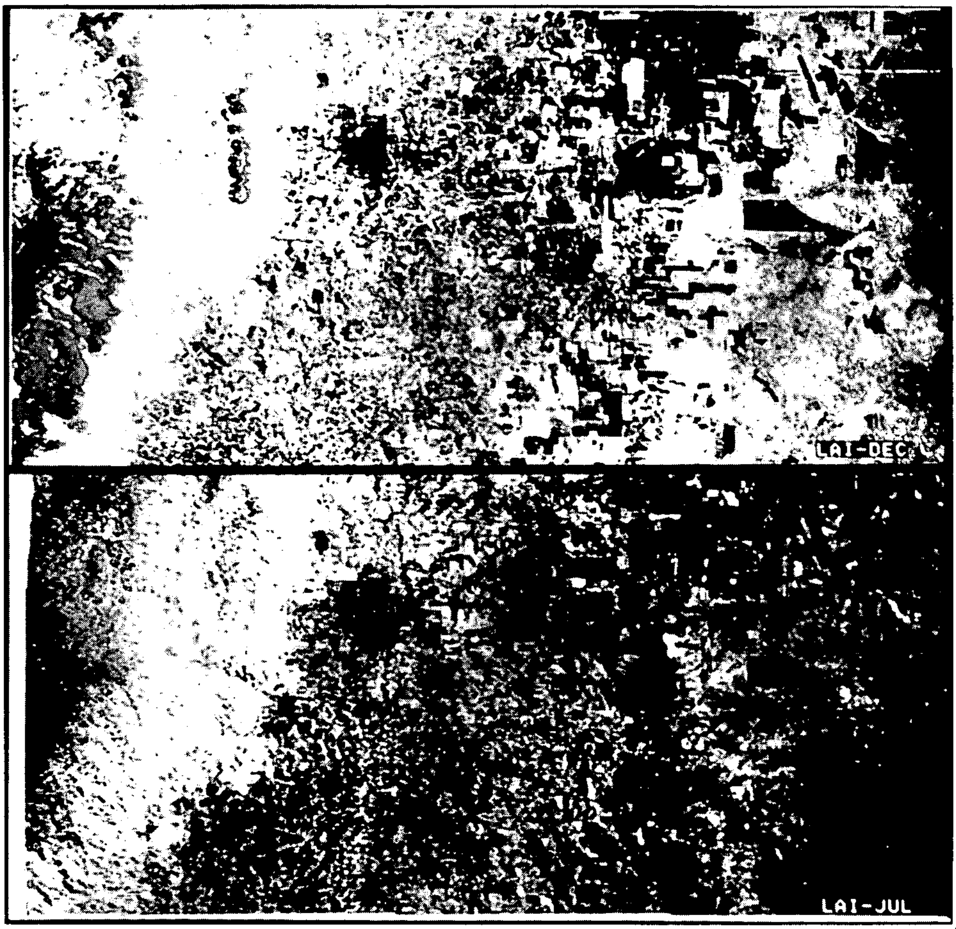


Figure 12.4 Physiography & geomorphology.

denudational, structural, karst, etc.), subdivided according to local relief, drainage density and pattern and toposequences. The information per geomorphological unit contains lithology, slope distributions, overland flow lengths, channel characteristics, surface resistance factors and the so-called 'morpho-erosion' forms. With the latter here is meant gully systems, landslides (soil flows, debris avalanches, slumps, etc.) and severe channel erosion. (Figure 12.4).

At reconnaissance or even semi-detailed scales, boundaries of the physiographic units and the geomorphological units usually coincide or can be made to coincide if one sacrifies formal legend conventions to some extent for the sake of a practical way of filling up a data base with relevant information (attributes). Sediment delivery ratios are estimated for each physiographic/geomorphological unit.



Map 2 Leaf Area Index transforms from Landsat b.5 and b.7 of the wet season (December) and the dry season (July), used for the look up table to produce the C factor map (USLE). Dark tones correspond to low LAI values, light tones to high values. On the left side the evergreen forest of the first ranges change into the arid zone (extreme left, dark toned, west of the clouds on the December image). Note the change in LAI in the drier plains in the east. Area NW Argentine.

Reasons for the split-up of the two types of information are:
- The GIS maps with the soil information will be used in other land evaluation procedures different from the maps with the geomorphological information.
- Too much information per mapping unit on a single map base leads to unwieldly legends and mistakes.
- The nature of the erosional processes is different in terms of causes, intensity per unit area and frequency (rate of work per event and magnitude of the event).
- For the sheet and rill erosion estimates, reasonably accurate approaches have been developed and applied to various parts of the world. This is not so for the morpho-erosional processes, for which quantitative estimates on a subjective basis have to be made.

12.6 Transformation

The physiographic information.
USLE factors (K), (L) and (S) are assigned to the elements of the associations of the mapping units. The (Gs) value for a mapping unit is determined by:

$$Gs = \Sigma(S.L.K(K_r).\%$$

where (K_r) is a resistance factor to be used in case slopes are steeper than the 22% limit of the (S) function of the USLE, as will be discussed below. (%) is the proportion of the area of the element in the unit.
This algorithm assumes no transport limitation and no deposition, which have to be considered in studies of catchments or units with catenas. This may be done by:
- Estimation of runoff by water balance methods for each element and unit;
- Application of the algorithms such as used by Morgan et al. The chart of Figure 12.5 shows how the input maps can be processed using the IGIPS software according to Morgan's site model. The test area in Sri Lanka was used.
- Use of the ANSWERS model (see below) for 'averaged' subcatchments in the mapping units.

The initial (Gs) value may be altered to incorporate transport limitations and deposition.

Earlier we mentioned some problems in transforming vegetation data into USLE cover factors. Actually, for most transformations difficulties are encountered, which is no wonder when one considers the physical dimensions of the input and the desired output. In sloping areas (i.e. hilly or mountainous areas) one runs into difficulties with even the best tested method, the USLE approach, notably with the slope function.

12.7 Effect of slope steepness in hilly terrain

There is very little known on the effects of slopes steeper than about 12° (22%) on sheet and rill erosion. In our test areas, however, many units have slopes much steeper than 12°, and to our knowledge no procedures exist to estimate the USLE (S) factor. It is useful to list the existing slope functions in order to judge if or till what steepness they may be extrapolated.

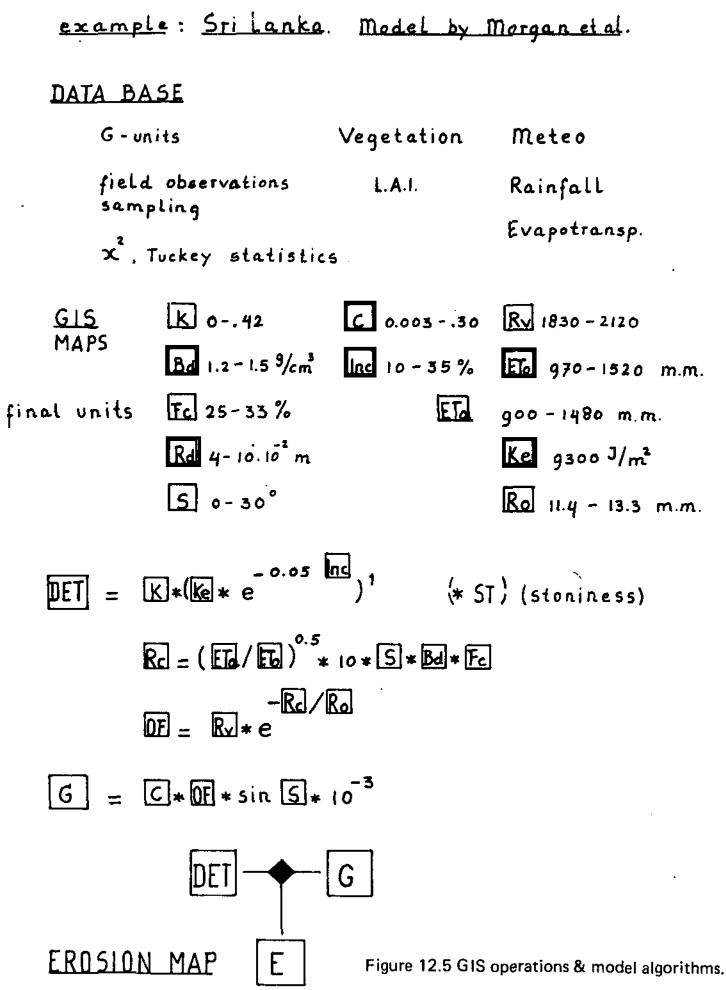


Figure 12.5 GIS operations & model algorithms.

In use are:

- polynomial functions (USLE) $E = 0.43 + 0.3s + 0.04s^2$
- tractive force formulae $E = \sin s$ (= velocity gradient)
- modified versions $E = \sin^{exp} s$ (exp. varies from 1.05–2.5)
- power formula $E = s^{exp}$ (exp varies from 0.7–2.0, mostly 1.35–1.5)

  $E = (s\text{-}s_c)^{exp}$ (s_c is critical steepness below which is no erosion occurs, exp. varies from 2–2.5
- linear relationships $E = c.s$ (c = constant)
- Horton function $E = \sin s/\tan^{0.3} s$

Except Horton's function, no others take into account a decrease for very steep slopes. This is required for the simple reason that rainfall, and thus overland flow, per unit of slope must vary with cos(s), assuming vertical rainfall. This leads to:

- modified version $E = \sin^{1.5} \cdot \cos s$

  or $E = \sin s \cdot \cos s.$

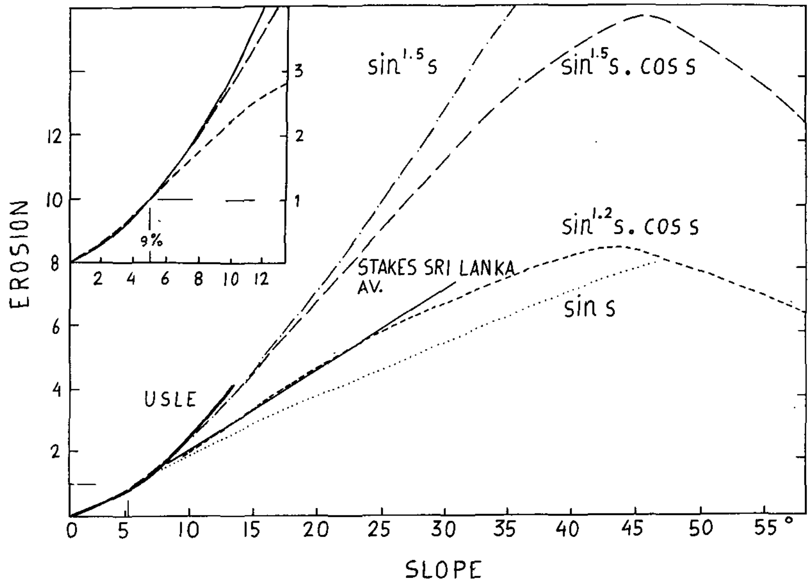


Figure 12.6 Comparison of slope functions, which are normalized for 9%=1 (USLES).

The graphs of Figure 12.6 show some of the above functions, normalized for 9% = unity, in order to maintain compatibility with the widely used USLE numerical values for the factor (S). Before a function is adopted, field evidences may be examined.

12.7.1 Field evidences for the slope function.

As stated above there is, to our knowledge, very little information present in a form useful for detecting the slope function. For the sake of comparison the following data is shown:

- Renner's histogram used by Horton, Figure 12.7.a.
- The graphs of Fletcher and Beutner based on thickness of top horizons eroded (Figure 12.7.b). Note the wide variation.

  Polynomial functions would describe the observed phenomena. The same is true for the laboratory determinations of some Canadian soils up to 30° slope steepness (Bryan).
- New data by Ziadi (Figure 12.7.c) for the Kasserine area in Tunisia, using the same classes as Renner.
- Stake measurements in the highlands of Sri Lanka by Dissanayaka (Figure 12.7.d) for a rainy season (points represented are randomly drawn from a larger population of measurement data).

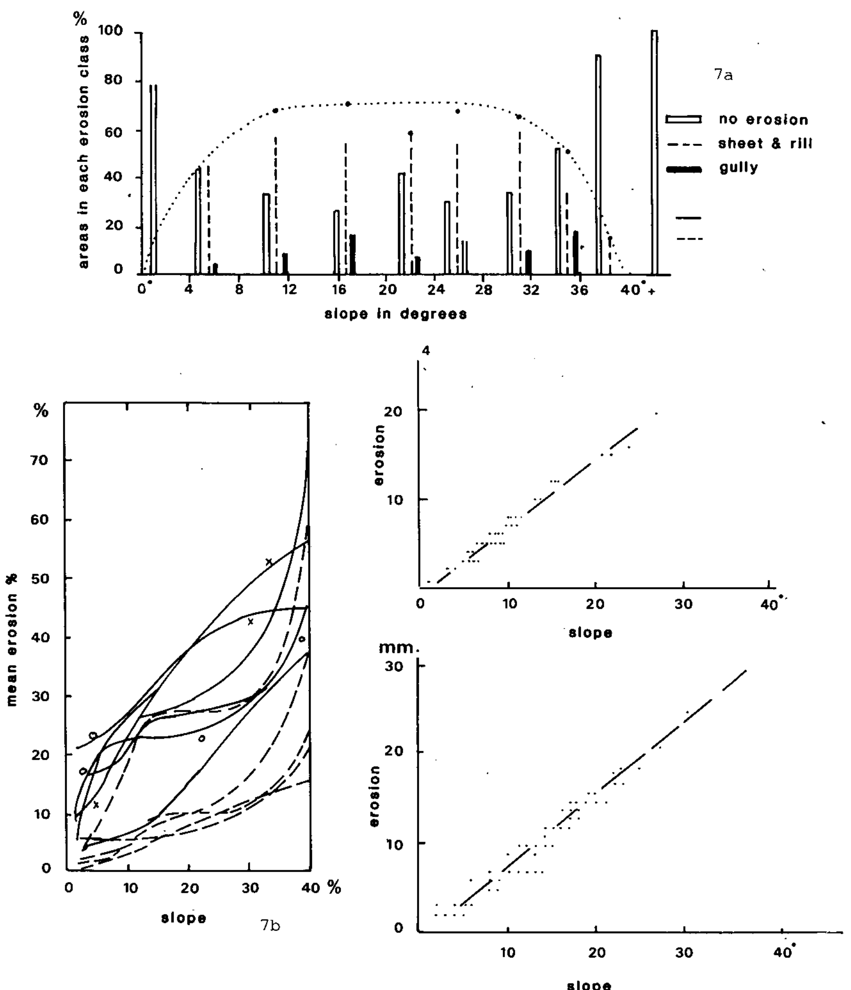


Figure 12.7 a - c Slope - erosivity relationships.

a. Idaho, USA (Renner, in Leopold, Wolman and Miller, 1964).
b. Upper Gila Watershed, USA (Fletcher and Beutner, 1941) dessert soils, brown soils at higher altitude.
c. Kandy Highlands, Sri Lanka (Dissanayake, 1977) erosion stakes.

SLOPE STEEPNESS & EROSION

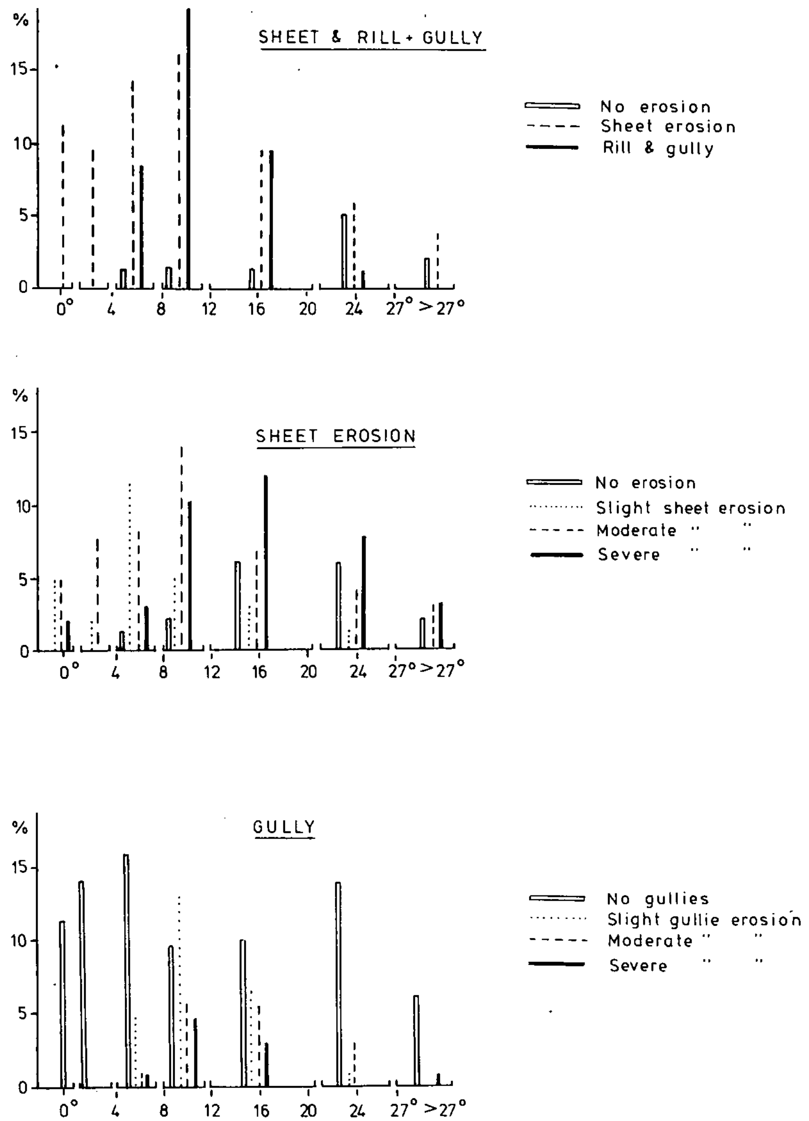


Figure 12.7 d Kasserine, Tunisia (Ziadi, in prep.) field estimates.

12.7.2 Evidence from sediment yields of mountain catchments

If the slope functions could be extended to steep slopes, very high sediment yields would be expected from mountainous terrain. The literature yields meager results, and mutual comparison is difficult. Some readily available data is shown in the table of Figure 12.8.

Figure 12.8 Sediment yields from mountain catchments.

author	area	remarks	ton/km^2/y	mass wasting important x present-
Ahmed 1960	N. Pakistan	Sed.yields large catchments,	500-3500	x
Kadomura 1980	Japan		500-13250	x
Meijerink 1977	Java, Merau River	Fly River	10000-≥25000	xx
Pickup et al. '81	Papua New Guinea,	0.37-4.05 mm/y	670-7400	x
Geiger 1957	Rocky Mountains	av.sed.yields 31 stations	260	
	NW. U.S.A.	av.sed.yields 6 stations	60	
	California	av.sed.yields 37 stations	370	–
	(zone along lower Mississippi	14 stations, lowland	5940)	
FAO 1954	Añdes. N. Argentina	rel. degree top soil loss	slight-mod.	
UNESCO 1974	Andes. N. Argentina.	rel. degree top soil loss	only small pockets servere	
Fournier 1960	Andes. N. Argentina	empirical formula	60-≥1000	
Strakhov 1967	Andes. N. Argentina	empirical formula	≤50-240	
FAO 1975	S. Marocco		≤500-1000	
Lal et al. 1977	Himalaya, Sutley River, Bhakra reservoir		1500	–
Meijerink, 1974	Himalaya Aglar River		≥2000	–
Irrigation Dept.	Sri Lanka, Mahaweli at Kandy		400-800(?)	

Except in regions with rapid tectonic uplift where mass wasting is an important if not dominant process, the rates do not seem to be excessive. It should be noted that some figures are estimates and that sediment delivery ratios are not available. A tentative conclusion is that there is no basis for an a priori extrapolation of the slope functions.

12.7.3 Evidence from erosion and vegetation on steeper slopes

Again there seems to be no abundance of data. The table of Figure 12.9 shows some values (mainly derived from M. Jansson's review). Consideration of the USLE suggests that the value of (S) cannot be very high in cases where the soil loss on steep slopes

Figure 12.9 Vegetation and erosion on steep slopes.

author	region	soil	annual rainfall	Slope %	Cover	soil less t/km^2
Starkel 1972	Murpur, Punjab		1092	25	grass 80%	545
					bare	1026
Temple 1972	Tenguru, Tanzania	deep red volc.soil	1070	32	grass, cut for hay	0 m^3/km^2
					maize	1200 m^3/km^2
					banana + mulch	50 m^3/km^2
					coffee, clean weeded	2240 m^3/km^2
Fournier 1967	Lake Alastra		978	20	grass 20% cover	1200
	Madagaskar		978	30	grass 100% cover	2.6
Glymph 1954	Pullman, Wash.	Palouse silt loam	528	30	perennial grass	17.9
				30	bare, untilled	4950
Ashida et al. 1981	Japan			18	cultivated, bare	2000-4000 t/km/y
				18	planted	1000-2000 t/km/y
				44	?	5,000

is low. The contents of the table show of course also the great influence of the cover factor.

12.7.4 Adopted slope-erosion relationship for sheet and rill erosion

From the above the following observations may be made:
- In the slope range up to 10° (17%) it makes little difference which equation is used (see Figure 12.6).
- The sin s.cos s.function is perhaps the most satisfactory one from a physical point of view, but gives too low values for the gentler slopes.
- The function sin $^{1.2}$s.cos s may be a reasonable compromise.
- The field data (Arizona, Tunisia, Sri Lanka) suggest region-specific relationships. The decline of erosion at steep slopes is related to increasing resistance of the surface to erosion on steep slopes. It is likely that the relationship is dependent on the erosional history. In semi-arid regions with hundreds or thousands of years of (accelerated) soil erosion the maximum erosion may be reached at 15-20°. In recently deforested humid tropical regions, the maximum may be reached within the range of 25-40°.

In order to maintain compatibility with the USLE procedures, the factor (k) may be used to describe the increasing resistance to rain erosion on steep slopes. To avoid confusion, we term the resistance factor k_r.

The factor (k_r) is dependent on slope steepness and the (k_r)
(s) relation, which is region-specific, could perhaps be assessed from field measurements of elements which can be readily determined in the field, such as thickness of lithosol, stoniness, frequency of rock outcrops.

In Figure 12.10 a compound resistance factor is shown, based on a weighted sı m of the elements, in the form of an accumulative frequency curve. That curve is used to calculate (k_r) as a continuation of the USLE (k) factor, valid for the soils on the

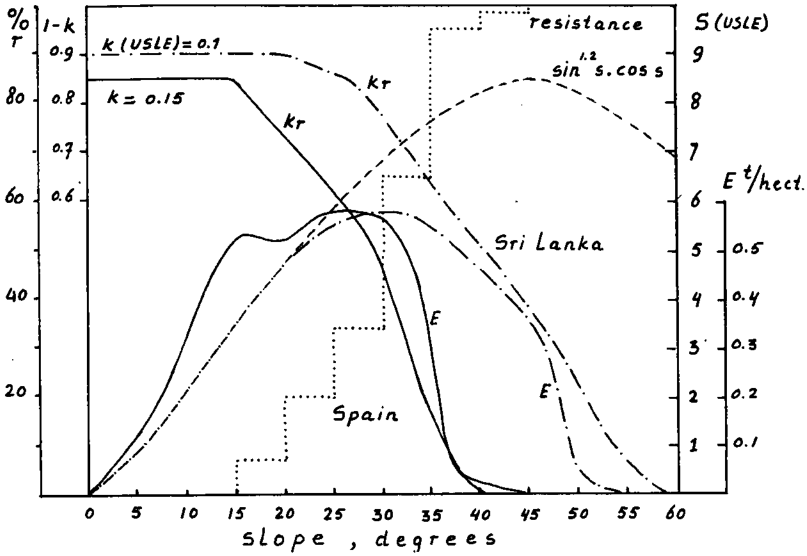


Figure 12.10 Slope function $\sin^{1.2}$ s x cos s. and resistance factor (k_r) compatible with USLE s soil factor (k), derived from cumulative frequency of accumulated resistance elements per slope class. Erosion (E) in tons/ unit area, results from k (k_r) x (S).

gentler slopes. Also shown in Figure 12.10 is an estimated and smoothened (k_r) (s) function for the test area in Sri Lanka, based on stoniness of former tea lands and adjusted for preliminary erosion rates, as estimated for root-exposure measurements on old tea bushes.
The resultant erosion (E) = $k(k_r)$.s is shown.
This approach, although empirical, results in decreasing erosion rates at steep slopes and may be accurate enough for a first evaluation. More research is required.

12.8 Transformation of the geomorphological information

The morphometrical information contained in the data base (frequencies of slope steepness, slope lengths) and the surface resistance factor, as derived from sampling in the units, is used for the transformation described above.

Of major concern in certain areas is the erosion and sediment yield contribution of the morpho-erosional processes such as gullying, sliding and channel erosion. The tables of Figures 12.11 and 12.12 give an overview of the possible range of magnitude and contribution. Included are short-term data (10 weeks, New Jersey) and long-term observations (34 years, California). As is well known, much sediment may be derived from only small parts of the catchments suffering from such erosion. However, not each and every gullied area, for example, is in an active state.
Estimates of the intensity per unit area may be made in several ways:
- If sediment yield data are available of some catchments, the rates may be assessed by estimating the contribution of sheet and rill erosion. The remainder is distributed over the parts affected by active morpho-erosion.

Figure 12.11 Debris/mudflows and landslides effect on sediment yield.

author	area	yield ton/km/y	
Pierson (1980)	N. Zealand	100–1,000xQ_s	surface wash rates
Ikeya (1981)	Japan	7,500 ton/km^2	
Rapp	Tanzania	650 ton/km/y	total yield
Meijerink (1977)	Java, sedimentary rocks	⩾25,000 ton/km/y	
	volcanic rocks	10,000 ton/km/y	
Gerasimov, &	Caucasus	290,000 ton/km	
Zvonkova (1974)	S. Caucasus	200,000 ton/km	
	S. Kazakhstan	50,000 ton/km	
Swanson, Swanson	New Zealand	40,000 ton/km/y	
& Woods (1981)	B. Colombia, N. Zealand	11– 100 m^3/km/y	forested
		111– 2,200 m^3/km/y	clearcut
		282–15,600 m^3/km/y	road, right of way
Kelsey et al. (1981)	N. California, earthflows 309		44% of gross erosion
	debris slides 544	853 ton/km/y	1% of area

Figure 12.12 Gully erosion rates.

author	area	mm/year	
Kelsey et al. (1981)	Nw. California	0.37	584 t/km/y 36% of gross erosion 4% of area
Yair et al. (1980)	S. Israel	very low	
Campbell (1977)	Alberta, Canada	4.51	
Gerson (1977)	Israel	2 –10	
Robinson (1977)	W. Iowa USA	5 –18	
Gong & Xiong (1980)	Loess, China	3.3–13	
Schumm (1956)	N. Dakota	20 –38	
	N. Jersey	10 –35	
Hadley & Schumm (1961)	U.S.A.	15 –45	
Strakhov (1967	world, small catchments, up to85 mm		
Trimble (1974)	Piedmont plateau USA	1.3–2.9	
	very severe sheet erosion destroyed by gullying	6.6	
Piest (1974)	Iowa, gully erosion 20% of total yield, percentage of gullied area 0-10% (?)		

- Field estimates of gully growth and active landslide volumes may be obtained using information with regard to age and frequency of occurrence from local inhabitants and comparing volume growth from old large-scale aerial photography and maps.
- In some regions where most of the coarse material in the rivers is supplied by morpho-erosion, estimates of the bed load may be attempted using particle size distributions, flow parameters and channel sections.

These estimates give also approximate results, but may provide an insight into the geographical variation and give an idea of the minimum rates.

It is evident that any improvement in estimation methods will have to be adopted.

The actual transformation in the GIS consists simply of mulipying areas affected by a factor representing the average intensity in tons per unit area area (i.e. a GIS pixel).

12.9 Trials, comparison and generation of the gross erosion map

As is shown in the chart of Figure 12.4, before the transformation of the input maps (Re), (C), Gs) and (Gm) into the gross erosion map (E), first the provisional results for a number of units are studied and compared with estimates obtained by other means such as mathematical models, regional or local rates.

12.9.1 Use of mathematical models

The models which we have used so far are the ANSWERS catchment model, developed by Beasly & Huggins, Purdue, and the simpler site model of Morgan, Morgan & Finney, Silsoe.

The ANSWERS model is particularly suited, being fully deterministic in nature, and the (C) map and derivates of the (Gs) map can be used as such as input in the model. The model produces:
- amount of erosion or deposition per pixel in the catchment;
- hydrographs of the surface runoff and the sediment concentration;
- sediment transport and sedimentation (with grain sizes) in the channel.

Because of lack of gauging data in the test areas, the calibration of the model we could do was limited to (a) peak flows with a recurrence interval of about 1 year, using estimated short-duration rainfall of the same frequency, and (b) using rainfall rates which do not result in noteworthy runoff and sediment transport in the rivers.

12.9.2 New automatic recorder

Very recently a cheap, small-sized fully automatic recording instrument is available. For river gauging the instrument is simply anchored to the bed at a suitable channel section, and can be left without any maintenance. Water-level readings are made at selected time intervals (minutes, hours) and stored in a built-in memory. The same type of instrument is used for rain gauging (prototype by ITC, commercial instrument by Siemens, Netherlands). A major bottleneck is thus removed for calibration of the modelled runoff in catchments in the various mapping units. Work is in progress to include sediment sampling.

12.9.3 Use of regional or local rates

Sediment yield data becomes more and more available in most parts of the world.

With the information of the (Gs) and the (Gm) maps it is possible to estimate the general levels of gross erosion, using the sediment delivery ratios estimated earlier. Furthermore, sometimes quantitative field estimates of erosion can be made from tree-root exposures, sediment surveys in small reservoirs, and so on.

12.9.4 Generation of the gross erosion map

Comparison of erosion rates, estimated in various ways, usually points out deficiencies in the tables of the (Gs) and the (Gm) data base. After corrections the gross erosion can be generated and edited, using once again image processing techniques and addition of drainage networks and topography.

12.10 Concluding remarks

It is too early to comment on the accuracy of the results obtained in the test areas, and the strength of the assemblage for simulation tasks beyond what is obvious to everyone. However, the following remarks can be made:

- Existing methods for estimation of erosion can be easily adopted by Geo-Information Systems, provided versatile facilities (hardware and software) are available to digitize, edit, transform and display the data.
- Vegetational, geomorphological and soil surveys, making use of interpretations of aerial photography and remote sensing (the conventional ITC-approach) are, together with climatic data, the basic sources of input information.
- Mathematical/physical models, preferably of a deterministic nature, can and should be an integral part of the data base and GIS operations. Either the GIS input maps can be processed according to model algorithms or the model results give improved values of factors for the transformations of the input maps.
- Adopted GIS formats and data-base procedures facilitate efficient multidisciplinary teamwork of specialists in the various fields.
- The forbidding strictness of the computer operations exposes weaknesses in the nature of the transformations, which in practice were usually covered by intuitive or empirical-associative approaches of the surveyor-specialist.

The assemblage, discussed here, takes a lenient view to the latter approach, but clearly indicates where improvements are required.

Acknowledgements

It is not for the sake of politeness that we thank and mention persons. Without their support we could never have reached the stage we are in now.

Three persons following M.Sc. courses at ITC did most of the work in the three test areas. They are V.M. Sayago (Argentina), whose persistence in compiling the information for all the transforms has to be admired; B. Emaruchi (Sri Lanka), who elegantly found a way to process the maps through the model of Morgan et al.; and K. Ziadi (Tunisia), whose precise field sampling and statistical analysis gives such

interesting results.

The many operations in the data base (frequency analysis, water budgets, statistics) could be made thanks to the participation and software of N.H.W. Donker (Geomorphology Group).

P. Stefanovic and D. Boonstra from the Cartography Department assisted in the digitalization and the conversion. The transformations of the maps in the GIS was done by B.G.H. Gorte and T. Bouw of the Computer Department with the versatile IGIPS (GIS) software which was developed by their department. Other transformations were done by Stefanovic using powerful cartographic software.

G. Reinink of the Image Processing Laboratory found a clever way of presenting the results using the remote sensing software, apart from his assistance in other processing, when needed.

The ANSWERS model was kindly given to us by D.B. Beasly, and the SWATRE model by R.A. Feddes.

The task of getting the hydrological models on the ITC VAX into operation with good graphical output was performed in a virtuose manner by R.X. Portier.

Finally, the colleagues at ITC, far more knowledgeable in soil, erosion, vegetation than we, advised us on the best estimates for the conversions, but they cannot be held responsible for the way we tried to follow it up.

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Discussion

P-Hernandez: Can you give any idea about the estimate of accumulative errors?

Meyerink: The calculations are checked after each stage, thus if rates are not realistic then the parameters are adjusted; if a sensivity analysis is carried out then the results may change dramatically.

Jungerius: How reliable is the map shown?

Meyerink: The map is reliable as it was based on many systematic, very detailed observations.

Bennema: What are the assumptions used in the model, and why are some parameters not taken into account; for example if pesticides were being used, what would be their influence on the soil cover and subsequently on the runoff; it appears that some parameters are taken to be the same over a number of years.

Meyerink: We have been working on a small scale and maps of this nature have little relevance at farm level; however we have calibrated our data against field observations and know which data are still needed if we want to apply the methodology on a large scale.

13 Modeling of soil productivity and related land classification

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13.1 Introduction

All land classification systems are based on models. In the past, these models have been relatively simple and largely intuitive. Nevertheless they depended on generalizations based on abstractions, models of the real world. The limitations of the human mind in handling many pieces of information simultaneously forced such classification schemes to use relatively few classes based on relatively few criteria. Computer modeling promises to liberate us from these restrictions and allow us to use an almost unlimited number of criteria for a continuum of land characteristics.

Computer modeling is, however, not without its shortcomings. While the human mind is limited in the number of items it can process at one time to arrive at a classification decision, it has almost unlimited capability to relate the decision to a vast amount of background information. We call this capibility 'experience' or 'common sense'. A computer has neither; it can consider only the factors that it has been programmed to consider and that are included in its data base. Hence, the computer may arrive at classification decisions that are logical within its decision system but are contrary to experience or common sense. Land classification, especially if applied worldwide, deals with very complex systems that respond to an extremely large and diverse number of factors. Hence, while a computer model can be invaluable in assisting land classifiers, its limitations must be kept in mind when it is used to make decisions. Results of computer models are not facts but rather projections that reflect all the shortcomings of data bases and algorithms.

The cost of computer hardware has largely ceased being a limiting factor in the application of computers to land classification. Within 3 years, for example, the Soil Conservation Service (SCS) of the United States Department of Agriculture (USDA) expects to have, in all of its field offices, minicomputers capable of using the models described in this paper. Appropriate software is a more serious limitation; data bases and especially cost-effective technology to enter geographic information of adequate detail will remain a major limitation for the use of computer models. People with broad practical experience who can intelligently develop and use computer models are also in short supply. Models must be used by professionals with strong backgrounds in the pertinent scientific disciplines. It is therefore appropriate that this meeting is taking place at an institution that is dedicated to the training of professionals and to cartography.

13.2 National models as a policy tool

This paper describes models used to estimate the impact of erosion on land productivity and farm production costs in the United States. It also describes plans for their future refinement and for their use in land classification and in making decisions on soil conservation. The Soil and Water Resource Conservation Act of 1977 (RCA) (USDA, 1981) directed the Department of Agriculture (USDA) to collect information on the current status of soil, water, and related resources; to appraise these resources; and to present an updated soil and water conservation program in 5-year intervals. The first appraisal was conducted in 1980, and the second is due in 1985. In implementing the RCA, certain key questions have forced the rapid development of computer models on relationships between erosion and soil productivity. What is the total cost of soil erosion? How will erosion affect the ability of American agriculture to produce food and fiber in the future? And how cost-effective are various alternative conservation policies?

The use of models for nationwide assessments rests on the availability of the following data bases:

a. The National Cooperative Soil Survey (NCSS), which has completed detailed mapping for about 66% of the land area of the country and is responsible for the other data bases listed here except the Natural Resources Inventory.
b. The map of major land resource areas (MLRA's). The United States has 189 MLRA's which are aggregated into 20 land resource regions (USDA, SCS, 1981). Major Land Resource Areas are areas that are characterized by a particular pattern of soils, climate, vegetation and land use and are used for statewide and national planning.
c. The NCSS Soil Interpretation Record (USDA, SCS, 1983) which includes data on interpretations and basic soil properties for about 13,000 soil series or variants of soil series.
d. The soil pedon record (USDA, SCS, 1972) which contains detailed soil laboratory data on more than 3,000 soil pedons, about 1,000 of which are available in computer readable form.
e. The USDA National Resources Inventory (NRI), conducted in 1977 and 1982. In 1982, this inventory (Lee, 1984) was based on a stratified random sample of 1,050,000 sample points on the nonfederal lands of the United States. For each sample point, information was collected on the factors for the Universal Soil Loss Equation (USLE) and Wind Erosion Equation (WEQ), land use and cover, soil classification, and many other environmental attributes. The NRI was designed to give information that is statistically reliable for state portions of MLRA's. Hence, the data can be analyzed by geographic units (MLRA's) and political units (states).

13.3 Erosion-productivity models (PI)

Two recently developed models are the Productivity Index (PI) model and the Erosion Productivity Impact Calculator (EPIC). Other erosion-productivity models have been developed for local use, but only these two have had widespread testing. They represent radically different approaches in their construction and application.

13.4 The productivity index model (pi)

The PI model was developed by W.E. Larson and F.J. Pierce (Pierce et al., 1984a) with various collaborators in USDA's Agricultural Research Service (ARS) and the University of Minnesota. For estimating the interaction of soil properties on productivity, it uses a model developed by Kiniry and associates (Kiniry et al., 1983) that indexes soils according to their suitability as an environment for root growth. The index is based on a statistical analysis of experimental plots in Missouri. The PI model uses available water capacity (AWC), resistance to root penetration as indicated by bulk density, and pH weighted by an idealized root distribution on 100 cm of soil:

$$PI = \sum_{i=1}^{r} (A_i \cdot C_i \cdot D_i \cdot WF_i)$$

where A is the sufficiency of available water capacity, C is the sufficiency of bulk density, D is the sufficiency for pH, WF is a weighting factor representing an idealized rooting distribution, and r is the number of horizons in the rooting depth. PI values are normalized to range between 0.1 and 1.0. The model assumes no fertility stress and climatic conditions similar to those under which the model was developed. Since the PI model is based on experimental results for maize (Zea Mays L.) and soybeans (Clycine Max L.), it reflects primarily the yield potential of these two crops on Mollisoils and related soils in the midwestern United States. The model uses data on soil parameters in the SCS Soil Interpretation Record (SOILS-5) for individual phases of soil series. For those properties given in ranges in Soils-5, the arithmetic mean of the range is used. The model recalculates the PI after 25, 50 and 100 years of erosion as the rooting function moves down in the soil profile because of erosion as estimated by the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1979). The model assumes a maximum rooting depth of 100 cm or the depth to a root-limiting layer identified in the SOILS-5 record. It uses information on soils, estimated erosion, and soil management for NRI sample points. The PI model has been used by Pierce (Pierce et al., 1984a) to project changes in cropland productivity due to erosion for several MLRA's in the midwestern United States. They concluded that the preponderance of deep, fertile cropland soils buffer the Corn Belt against productivity changes due to erosion. They point out, however, that erosion may cause devastating changes in productivity on some soils with more than 6 per cent slope having unfavorable subsoil horizons.

13.5 The erosion-productivity impact calculator (EPIC)

EPIC was developed by a team of scientists of USDA's Agricultural Research Service (ARS) and Economic Research Service (ERS) under the leadership of J.R. Williams at Temple, Texas (Williams et al., 1984). More than 15 scientists in various disciplines contributed to the development of the model. In contrast to the PI model, the EPIC is a deterministic or process model. It simulates potential productivity with chemical and physical processes in the soil and the plant that influence the growth of specific crops. EPIC uses a daily weather simulator over a 100-year period. It simulates the following processes and attributes:

Hydrology:	Surface runoff	Runoff volume Peak runoff rate Percolation Lateral subsurface flow Evapotranspiration Snowmelt
Weather:		Precipitation Air temperature Solar radiation Wind
Erosion:	Water	Rainfall energy Runoff volume Peak runoff rate Crop management Erosion-control practices Slope length Slope gradient Soil erodibility Irrigation
	Wind	Erodibility index Climate Ridge roughness Field length Vegetation
Nutrients:	Nitrogen	In surface runoff Leaching Loss in evaporation Transport in sediments Denitrification Mineralization Immobilization Crop uptake Fixation Addition from rainfall
	Phosphorus	Soluble in runoff Adsorbed on sediment Mineralization Immobilization Cycling Crop uptake
Soil temperature:		Surface soil Albedo Depth function
Crop growth:	Potential growth:	Photosynthesis Daily biomass Leaf area index Yield fraction Root sloughing Root weight distribution Rooting depth

	Growth constraints	Moisture stress Temperature stress Nutrient stress Root growth stress
Tillage:		Tillage mixing Bulk density change Ridge height Surface roughness
Plant environment control:		Irrigation Fertilization Liming Pesticides.

So far, EPIC can model the growth of maize, grain sorghum, winter and spring wheat, barley, oats, sunflowers, soybeans, alfalfa, cotton, peanuts, and grasses. Work is in progress on a number of other crops, including some tropical crops. EPIC allows for several tillage systems, such as fall plow, spring plow, and conservation tillage including no-till, and for a variety of harvest methods that remove different amounts of residues from the field. The model simulates the removal of surface layers by water erosion using the Onstad-Foster (Onstad and Foster, 1975) modification of the USLE and an adaptation of the Wind Erosion Equation (WEQ) (Skidmore and Woodruff, 1968). It makes adjustments in the properties of the surface soil due to return of organic matter from different management systems. The model user can specify the degree of tolerable moisture and nutrient stress before irrigation or fertilizer application. The user also can specify certain restrictions on the time and frequency of irrigation or fertilizer applications.

EPIC requires detailed soil characterization data that include the major chemical and physical properties of soils. It calculates not only the projected impact of erosion on the productivity of the selected crops but also the amounts of fertilizer needed under a specified level of nutrient stress. These amounts depend partly on the amount of erosion that is occurring.

The model is relatively efficient and the required storage capacity is relatively low, about 280 K. Using the cheapest night rate at a University computing center, a 1-year simulation can be run on a AMDAHL 470 computer 15¢. The number of permutations and hence the costs can be considerable, however, if the model is used to simulate the impact of erosion on many soils, several crops, and several rotations and management schedules.

The model was tested initially by comparing runs of the model against yield data of some 200 experimental sites throughout the United States. Later, as part of the RCA analysis, the results were judged subjectively for 'reasonableness' by experienced SCS personnel. In general, the model gave surprisingly reasonable yield projections except for soils with a wetness limitation, especially one caused by factors other than soil characteristics. Although EPIC was primarily developed for making estimates of the impact of erosion on soil productivity, it has considerable potential for estimating the productivity of various soils under given management systems, for improving our understanding of factors that influence soil productivity, and for transferring results from research plots to farmers' fields.

For the purposes of the 1985 RCA analysis the model was run on eight soil pedons for each MLRA to represent eight groups of subclasses of the USDA land capability classification system. These pedons were selected subjectively by appropriate SCS personnel. This was not an ideal procedure but was unavoidable under the time constraints for the 1985 RCA report. The need to select one pedon to represent large areas of land is a major shortcoming of the model. Since EPIC is being used primarily to test the impact of various management options, the adopted procedure is justifiable. In spite of the computational efficiency of the model and the small number of pedons, running all of the permutations of soils, rotations, tillage systems, and conservation practices for the intended national analysis (630,000 100 year runs) became prohibitively expensive. Hence, the national RCA analysis was executed using Erosion-Productivity Indices as described in the following.

13.6 Erosion-productivity indices

The developers of the PI and EPIC models have both proposed erosion-productivity indices. Both sets of indices use the slope of the erosion-productivity regression as a measure of the sensitivity of the soil to erosion. Larson (Larson et al., 1983) has designated the change of PI as a function of depth of erosion as the 'vulnerability curve'. Pierce et al. (Pierce et al., 1984b) have proposed a vulnerability index, V, based on the 50-year decline of soil productivity due to erosion estimated by the PI model. Pierce also proposed a soil loss tolerance value, T1 (distinct from T2, which would be determined by environmental considerations), that is based on V and the economically tolerable productivity loss over a predetermined planning horizon.

A similar concept was developed for EPIC, partly to increase the efficiency of the model (Putnam et al., in press). In this approach the productivity loss attributed to erosion was determined for individual soils and crops by running EPIC twice, once assuming a highly erosive management and once assuming no erosion. The difference between the two productivity estimates is highly variable, depending on the weather conditions assumed for the year by the weather generator, but there is a trend with time if there is significant erosion and the soil is sensitive to erosion. The slope of the regression of productivity loss as a function of tons of soil loss is designated as the erosion productivity index (EPI). The EPI and similar functions that give the dependence of fertilizer rates and management practices on erosion were used to generate the multitude of values needed for the RCA analysis.

EPI and V indices calculated from EPIC and PI for a number of soils in the Corn Belt gave reasonably comparable results. Both approaches to erosion productivity modeling have their advantages. If experimental data on factors influencing soil productivity are available for a given area, an adaptation of the PI model can be developed rapidly. It will give reasonable results for the given soil-climate-management environment but cannot be transferred to different environments unless adapted to local data. Just how far a given set of parameters can be moved is obviously open to question. An attempt to apply the PI model with the Midwestern U.S. coefficients to soils of the Tropics had very limited success (Rijsberman and Wolman, 1984).

EPIC, or the simplified erosion productivity index (EPI) developed from it, should not suffer from narrow geographic limitations. If the assumptions underlying the model are indeed universally applicable. EPIC or EPI can be expected to give reasonable results provided that laboratory and weather data are of acceptable quality. So far, EPIC has had very limited testing outside the United States.

Neither model considers the impact of erosion on surface soil properties that control water infiltration capacity, an important factor for which there seems to be no generally accepted method of prediction. The Onstad-Foster model of erosion prediction (Onstad and Foster, 1984) that is being used in EPIC with daily weather data provides erosion and runoff estimates for critical seasonal erosion periods. This capability should be of considerable value in the planning of conservation programs. Both models have considerable promise for an improved classification of land relative to its sensitivity to soil erosion.

13.7 Current developments

The Universal Soil Loss Equation, like the PI and EPIC models, deals with soils that have vertical but not horizontal dimensions. They deal with points rather than with areas and they do not address deposition of soil or addition of water to the soil profile due to run-on. They model only losses and not the interplay of losses and gains that takes place in the real world.

An attempt to remedy this situation was made by Perrens et al. (Perrens et al., 1984). They combined elements of EPIC with the erosion component, EROS2, of a small-watershed hydraulic model, CREAMS (Foster et al., 1977).

EROS2 uses characteristic rainfall and runoff rates for individual storms across a landscape of individual land segments that may differ in soil, slope, cover, and management. Sediments leaving individual segments are made up of the sediments entering the segment, plus net erosion minus net deposition. Computations are made by particle size class to simulate selective erosion and deposition of individual size fractions.

The two models were linked using the daily time steps for weather, crop growth, runoff and erosion from EPIC and erosion and deposition simulation along land segments from EROS2. Coefficients were adjusted in both models to give the same soil for a particular uniform land profile.

The combined model was used to study erosion and productivity changes of a glacial till soil of uniform thickness (Miami silt loam, a fine loamy, mixed, mesic Typic Hapludalf). Miami is an extensive soil in northern Indiana and Illinois. The study assumed continuous maize on an idealized landscape of concave, convex, complex, and uniform slope. Each slope segment had an average slope of 5 per cent and a length of 100 meters. The nonuniform slopes varied in steepness from 11 to 1 per cent. The average annual erosion rate for the uniform slope was 40 t/ha, which agreed with the USLE estimate for the study condition. Figure 13.1 shows the assumed shape of the slopes and Figure 13.2 the relative erosion and deposition rates for individual slope segments.

On the uniform slope, erosion increased gradually from zero at the top of the slope to 1.6 times the average erosion rate at the bottom. For the convex slope, the erosion rate increased greatly with distance from the top. For the concave and complex slopes, high rates of erosion in the top parts were followed by lower rates of erosion or by deposition in the lower parts. Total soil loss from the convex slopes was 2.2 times that of the uniform slope. Although considerable relocation of soil by erosion and deposition occurred on the concave and complex slopes, the amount of soil leaving

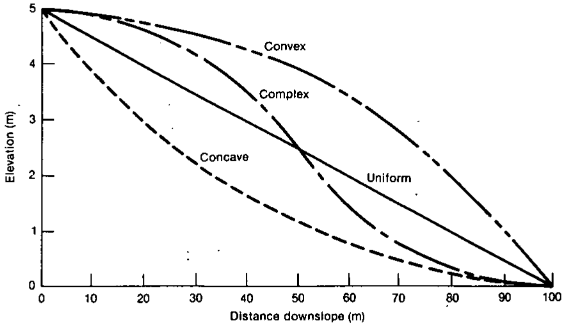

Figure 13.1 Examples of slope shapes.

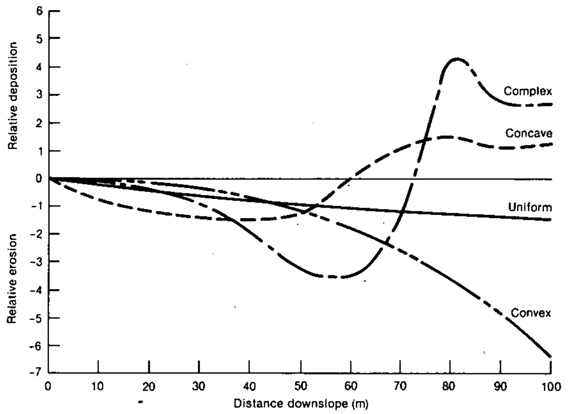

Figure 13.2 Influence of shape on erosion in various segments of a slope.

the last segment was only 16 per cent of that of the uniform slope for the concave, and 27 per cent for the complex slope.

The relative productivity change due to erosion of individual slope segments was calculated from EPIC, normalized for average weather conditions. For the Miami soil, EPIC predicts a rapid decrease in productivity to 90 per cent of that of the uneroded soil for the first 60 mm of soil loss. It then predicts a gradual decline to 85 per cent for the next 240 mm of soil loss. The effect of deposition on some slope segments, had to be estimated. Based on EPIC runs and experimental evidence, it was assumed that 50 mm of deposition would increase productivity to 120 per cent of the original and then cause no further change. Figure 13.3 shows the changes in productivity over time for the various slope configurations. As expected, productivity losses were largest for convex and uniform slopes and, under the given assumptions, were very small for the complex and concave slopes. Productivity changes could have been quite different if different assumptions had been made for the soil or the slope configuration, but the evidence clearly suggests that slope shape could considerably influence erosion and consequent soil productivity changes. These results suggest that the shape of slopes may be an important consideration in classifying sloping lands and should be considered in future systems of land classification.

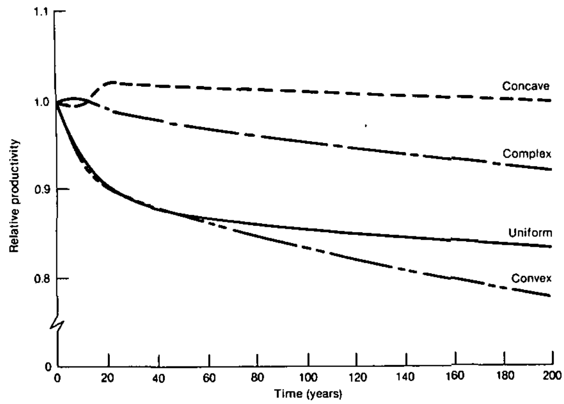

Figure 13.3 Influence of the slope on the impact of erosion in various segments of a slope.

This model assumed slopes that were uniform normal to the slope. In the real world slopes are, of course, nonuniform in all directions. Lateral non-uniformity leads to the concentration of runoff and the formation of shallow gullies that are readily obliterated by cultivation but that may contribute considerably to erosion. Erosion and deposition also tend to make soils more variable. Greater variability increases the cost of crop production and the danger of pollution because crops cannot use fertilizers and other amendments equally in all parts of a field. This cost of soil erosion has not been studied extensively.

13.8 Conclusions

Modeling promises to bring about major changes in the way land classification systems are developed and used. By forcing us to look at aspects of land classification that we had not considered before, models will lead to better systems or, at least, a rigorous examination of existing systems. Modeling will also allow us to treat more complex systems and to look at the interactions of components of natural landscapes and management systems. Finally, modeling will allow us to adapt classification systems to the needs of particular areas and farming systems much more readily than in the past.

Models cannot, however, classify land for us. Like classification systems, models can reflect only the conditions and processes that their creators anticipated. People who design models must therefore have broad practical experience if their models results are to be meaningful in many settings. People who use models must understand their strengths and shortcomings for the application at hand. If models are to be used successfully in land classification they must be one of the tools of every land classifier and not the exclusive domain of professional modelers.

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14 Soil potential for maize production in Weakley County, Tennessee

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14.1 Introduction

In the U.S. until recently most soil interpretations were expressed solely as degrees and kinds of soil limitations. Warnings about possible hazards are valuable, but those who plan the use and management of land are left with the task of finding feasible corrective measures for individual kinds of soil. The soil potential approach identifies these measures and any limitations that might continue after the measures are installed. Soil potentials are being used increasingly at the local level where thorough evaluations are needed.

Soil potential ratings indicate the relative quality of a soil for a particular use compared with other soils in a given area. The ratings consider yield or performance level, relative cost of applying modern technology to minimize the effects of any soil limitation, and adverse effects of any continuing limitations.

The Soil Conservation Service (SCS) has adopted the Soil Potential Index (SPI) approach to:

- Provide a common set of terms applicable to all kinds of land use for relative ratings of soil quality for a particular use.
- Identify effective and feasible corrective measures.
- Enable local preparation of soil interpretations that are based on locally established criteria.
- Provide information about soil that emphasizes feasibility of use rather than avoidance of problems.
- Assemble in one place information on soils, corrective measures, and the relative costs of corrective measures.
- Make soil surveys and related information more useful in resource planning.

SCS encourages preparation and use of soil potential ratings in those cases where they will help achieve better use of soil and water resources. The ratings are prepared by an interdisciplinary working group of soil scientists, soil conservationists, engineers, and other specialists. Technical experts other than soil scientists must have a major role and concur in technical decisions and ratings.

SPI is used to rank soils according to their potential, by the general formula:

$$SPI = P - CM - CL$$

where P is an index of the performance or yield standard for the land use or crop in the area, and, using P as the performance standard, CM is an index of the costs of corrective measures, and CL is an index of continuing limitations (6).

14.2 P – the performance standard

P is an index of the performance or yield standard for the land use or crop in the area. The definition of P includes a set of assumptions about the level of management and specific management practices used. Typically, the standard is set on the least expensive combination of practices which will achieve the yield standard on the most productive soils. One objective of the soil potential approach is to help assure that the latest, most effective technology is considered in the management of each kind of soil. However, emphasis is given to technologies thought to be feasible by local farmers and soil conservationists and other professional agricultural workers in the area.

The statement of assumptions and the definition of the performance standard is similar to the definition of the land utilization type (LUT) of the FAO Land Evaluation procedure (1,2). However, P as typically defined provides a more detailed set of assumed management practices than LUT.

The following definition of P was established for Weakley County:
The soil is intensively managed for production of maize for grain. The cropping sequence followed is maize – winter wheat with double-cropped soybeans, i.e. maize is produced every other year. The maize is seeded using no-till technology. Just after the maize is harvested, the stalks are disked and winter wheat is planted. After wheat harvest, the soybeans are seeded using no-till. An optional cropping sequence may include no-till corn annually. However, soil erosion is held within the soil loss tolerance.

Soils are managed for maximum net farm income using a high level of management. All crop residues are returned to the soil and lime and fertilizer are applied according to the results of soil tests. Farming operations are timely and carried out to minimize losses due to weeds, insects, and diseases.

The standard yield for maize is 7,840 Kg/ha (125 bu/ac) at 12% moisture. Any practices needed in addition to those indicated in the definition of P, such as strip-cropping, terracing, or drainage, are considered to be corrective measures which add to the cost of production, but which are needed to maximize net farm income while meeting the soil conservation objectives.

14.3 CM – corrective measures

CM reflects the costs or relative difficulty of installing corrective measures to overcome or minimize the effects of soil limitations. One of the purposes of the soil potential approach is to help assure that the latest, most effective technology is considered in the management of each kind of soil. Emphasis is given, both in the definition of P and in the identification of CM, to feasible technologies available to local farmers.

CM is an index of added cost, over and above the standard set of management practices assumed in P. CM is zero where the only management needed is that defined as standard (P). Below, CM's are discussed for the three major limiting soil properties – slope and erosion, wetness, and flooding.

14.3.1 Slope and erosion limitations

In Weakley County, soils with slopes up to about 20 per cent are being cultivated. Soil erosion on many sloping areas exceeds 50 tons/ha/yr. The soils are rated on the basis of farming systems which will hold soil erosion to within soil loss tolerance.

Three of the sloping soils, Grenada, Lexington, and Loring have soil loss tolerances of 6.7 t/ha/yr (3 tons/ac/yr) and the other soil, Memphis, has a soil loss tolerance of 11.2 t/ha/yr (5 tons/ac/yr).

Everything else being equal, the nearly level soils, i.e. those with slopes of less than 2%, have higher soil potential than the sloping soils because practices to control soil erosion are not needed. The no-till farming system, devised mainly as an erosion control practice, is thus not needed. Due to the cost of extra chemicals, the no-till system costs $18/ha more than the conventional system, and this added cost is thus required on the sloping soils, but not on the level ones.

Another conservation practice related directly to slope is grass waterways. The more sloping the cropland, the greater the length of waterways needed, as noted in Table 14.1. The waterways are assumed to be 10 m wide. Thus, on the 12 to 20 per cent slopes where 98 m of waterways are needed per ha, the land used for waterways represents 10 per cent of the total land area. Proportionately smaller amounts are needed on less sloping areas. Annual maintenance of waterways is treated as a continuing limitation, as indicated in Table 14.1. Annual clipping of weeds and seeding of small eroded spots is included.

The Universal Soil Loss Equation (USLE) was used to determine the required conservation practices. The following values were used:

R	–	Rainfall factor	250
K	–	Erodibility factor	
		Grenada, Lexington, Loring and Memphis soils	0.49
LS	–	Topographic factor	
		2- 5% slopes – L 23 m, S 4%	0.36
		5- 8% slopes – L 23 m, S 6%	0.58
		8-12% slopes – L 15 m, S 10%	0.97
		12-20% slopes – L 15 m, S 16%	2.01
C	–	Corn – Wheat/Soybeans sequence	0.078
		Corn – Wheat/Soybeans – 3 years of Meadow sequence	0.015

The calculation of the necessary supporting conservation practices was then possible, starting with a practice factor of 1.0 for up-and-down the hill farming. The following erosion rates were calculated for the various combinations of slope and K factors:

2 to 5% slopes,	K 0.49	7.6 t/ha/yr (3.4 Tons/ac/yr)
5 to 8% slopes,	K 0.49	12.4 t/ha/yr (5.5 Tons/ac/yr)
8 to 12% slopes,	K 0.49	20.7 t/ha/yr (9.2 Tons/ac/yr)
12 to 20% slopes,	K 0.49	43.0 t/ha/yr (19.2 Tons/ac/yr)

Based on the calculated erosion rates it is concluded that the soils on 2 to 5 per cent slopes are adequately protected without strip-cropping and terracing, but the more sloping soils are not.

For the 5 to 8 per cent slopes, contour strip-cropping, with the edge of the strips along the middle of the short slopes, reduces the practice factor to 0.6 and holds soil

Table 14.1 Corrective measures and continuing limitations for slope and erosion.

Per cent Slope	Degree of Limitation	Effects on Use	CM Corrective Measures			CL Continuing Limitation		
			Kind	Cost	Index	Kind	Cost	Index
0-2%	None	None		$/ha			$/ha	
2-5%	Slight	Soil erosion	Extra chemicals, no till	$18	3			
			30 m of Waterway/ha	$ 5	1	Waterway Maintenance	$3	1
5-8%	Moderate	Soil erosion	Extra chemicals, no till	18	3			
			55 m of Waterway/ha	10	1	Waterway Maintenance	5	1
			Strip-cropping	8	1			
8-12%	Severe	Soil Erosion, Difficult Machinery operation	Extra chemicals, not till	18	3			
			78 m of Waterway/ha	15	2	Waterway Maintenance	8	1
			Stripcropping	8	1			
			Terracing	55	8	Terrace maintenance	6	1
						Extra machin-ery cost	5	1
12-20%	Very severe	Soil erosion, Difficult Machinery operation	Extra chemi-cals, no till	18	3			
			98 m of Waterway/ha	20	3	Waterway Maintenance	10	1
			Cost of estab-lishing meadows	$80	11			
						Extra machin-ery costs	10	1

erosion to less than the soil loss tolerance on all the soils. On the 8 to 12% slopes, terracing is also required, in addition to contour stripcropping. The soils on 12 to 20% slopes are too steep for terracing, however. To avoid exceeding the soil loss tolerance on these strongly sloping soils, it is necessary to use two years of meadow in the cropping sequence. Thus the cost of establishing the meadow is counted as an added cost. No assumption was made about the relative values of the maize crop and the meadow crop. Because of the low estimated maize yields on these soils, there probably is little economic advantage for the maize.

14.3.2 Soil wetness limitations

Seasonal soil wetness which interferes both with crop growth and management occurs on some soils of the uplands and others on the floodplains in Weakley County. Corrective measures and continuing limitations for such wetness are indicated in Table 14.2.

Local practices for soil drainage in Weakley County are different in the floodplains than on the uplands. Due to the fact that flood waters compound drainage requirements on the floodplains, more extensive practices are used. On moderately well drained and somewhat poorly drained upland soils, open drainage ditches are not considered feasible locally in spite of lower average yields of maize due to wetness. Local farmers recognize the likelihood that drainage would increase crop yields on the seasonally wet upland soils, but do not believe that the increased returns would be sufficient to offset the cost of ditching. This is not true for the poorly drained Routon soils of the uplands and stream terraces.

The ditches used for drainage are about 0.8 m deep. Installation cost is $0.53/m and the length of ditch per ha ranges from 150 m on the poorly drained soils to 40 m on the moderately well drained soils. In addition, about 40 m of outlet ditches are needed per ha on the poorly drained Waverly soils of the floodplains.

14.3.3 Flooding limitations

A large acreage of soils used for cropland in Weakley County are subject to flooding. As indicated above, special drainage practices are used on the wetter soils of the floodplains. No other special practices are used.

Most of the floodplains are protected by flood control structures. An assessment of $5/ha is paid on these areas, and is thus counted as a continuing limitation (CL) index of 1 on all soils of the floodplains.

14.4 CL – continuing limitations

CL is an index of limitations continuing after feasible CM have been applied. The continuing limitations have adverse effects on social, economic, or environmental values. They can be of three basic types:

1. annual or periodic costs of maintenance, failure or difficult operations;
2. offsite damages from sediment or other forms of pollution;

Table 14.2 Corrective measures and continuing limitations for seasonal soil wetness.

Soil drainage class	Degree of limitation	Effects on use	Corrective measures			CL continuing limitation		
			Kind	Cost CM	Index	Kind	Cost	Index
Well	None	None		\$ha				
Moderately well	Slight	Wet pocket delays planting						
a. Floodplains			Open ditches 40 m/ha	20	3	Maintain ditches	18	3
b. Upland			None feasible					
Somewhat poorly	Moderate	Delayed planting and harvest						
a. Floodplains			Open ditches 115 m/ha	60	9	Maintain ditches	45	6
b. Upland			None feasible					
Poorly	Severe	Delayed planting and harvest						
a. Floodplains			Open ditches 150 m/ha	80	11	Maintain ditches	82	12
			Outlet ditches 40 m/ha	28	4			
b. Upland			Open ditches 150 m/ha	80	11	Maintain ditches	65	9

3. substandard performance, including low yields.

As noted in Tables 14.1 and 14.2, CL in Weakley County includes the maintenance of ditches, waterways, and terraces, and also the difficulty of machinery operation on slopes of more than 8 per cent.

14.5 Soil potential indexes

The values of the indexes presented in Tables 14.1 and 14.2 were determined based on setting unity at the value of a bushel of corn. This value was set at $3 to approximate the current market price. Also, as the original calculations were carried out on a per acre basis, it is necessary to use a 2.5 multiplier. Thus unity is set at $7. To avoid decimals all indexes are rounded to the nearest whole number, e.g., the index for a cost of $18 is 3 (Table 14.1).

Based on the criteria established, as presented in Tables 14.1 and 14.2 each of the soil map units in Weakley County was rated as illustrated in Tables 14.3 and 14.4. The specific soil and site conditions of each soil map unit were determined for each evauation factor, i.e. slope, drainage class, and flooding. Corrective measures and their costs, and continuing limitations and their index, were established for each limiting soil feature.

The two soils chosen as examples in Tables 14.3 and 14.4 are highly contrasting. The Memphis series is a well drained, sloping soil formed in loess (Typic Hapludalf fine silty, mixed, thermic). It is highly erodible. The Waverly series, however, has no erosion problem, but is severely limited due to wetness and flooding (Typic Fluvaquent, coarse silty, mixed, thermic). No corrective measures judged locally to be feasible are available to fully overcome the limitations and as a result yields are seriously reduced.

The Memphis soil has relatively inexpensive CM, but has a large CL that results largely from substandard yields. Yields are below standard largely because of past erosion and lowered available water capacity and SPI is 79. The Waverly soil, however, in spite of expensive drainage practices, still has low yields; SPI is only 27.

The soils of Weakley County are arrayed in Table 14.5 according to their soil potential index. The indexes range from a high of 124 down to a low of 27. They indicate both the productivity, limitations in use, and difficulty of achieving the indicated level of production, using feasible measures and still meeting soil conservation objectives.

The soil potential ratings for Weakley County place the soils in an array similar to but not the same as the order of declining crop yields. However, there are notable exceptions. For example, the Routon soils are more productive than the Lexington soils on 8 to 12% slopes and the Loring and Grenada soils on 5 to 8% slopes, but has a lower soil potential due to the high drainage costs. Also, the occasionally flooded Falaya soils have higher productivity than the Memphis soils on 2 to 5% slopes, but a lower soil potential index. A recently completed analysis of soil potential for soybeans in Virginia showed more striking differences between productivity and soil potential index; some soils with high productivity were shown to have low potential (4).

Soil potential ratings provide an evaluation of numerous factors of importance to the land use and soil conservation, as illustrated by the information in Table 14.5.

Table 14.3 Derivation of soil Potential Index for Memphis silt loam, 5-8% slopes, severely eroded.

Evaluation Factors	Soil and Site Conditions	Degree of Limitation	Effects on Use	Corrective Kind	Measures Index	Continuing Kind	Limitation Index
Slope	5-8%	Moderate	Soil erosion	Extra chemicals, no till	3		
				55 m of waterway/ha	1	Waterway maintenance	1
				Strip-cropping	1		
Drainage	Well drained	None					
Flooding hazard	None	None					
						Substandard yield	40
				Totals	5		41

P CM CL SPI
125 − 5 − 41 = 79

Table 14.4 Derivation of Soil Potential Index for Waverley silt loam, frequently flood.

Evaluation Factors	Soil and Site Conditions	Degree of Limitation	Effects on Use	Corrective Measures Kind	Corrective Measures Index	Continuing Limitation Kind	Continuing Limitation Index
Slope	0-2%	None	None				
Drainage	Poorly drained	Severe	Delayed harvest and planting	Open ditches 150 m/ha	11	Maintain ditches	12
				Outlet ditches 40 m/ha	4		
Flooding	Frequent (likely to occur annually)	Severe	Delayed planting, crop damage	None feasible		Annual assessment	1
						Substandard yield	70
				Totals	15		83

P	CM	CL	SPI
125 –	15 –	83 =	27

Table 14.5 Soil potential indexes, land capability subclass, yield index and related ratings of soils in Weakley County, Tennessee.

	Soil erod. factor K	Soil loss tolerance T	CM + CL (exclude reduced or substandard yield)	Substandard yield CL	Yield index	Land cap class	Soil Potential SPI Index	Rating Classes
Collins sil, rarely flooded	1/	1/	6	0	100	I	124	Very high
Collins sil, occas. flooded	1/	1/	5	0	96	IIw	120	
Ochlockonee sil occ. flood	1/	1/	5	15	85	IIw	105	
Falaya sil, rarely flooded	1/	1/	15	10	88	IIw	100	
Memphis sil, 2-5%	49	5	3	25	77	IIe	97	High
Falaya sil occ. flooded	1/	1/	14	15	85	IIw	96	
Lexington sil, 2-5% sl.	.49	3	3	30	73	IIe	92	
Loring sil, 2-5% sl.	.49	3	3	30	73	IIe	92	
Memphis sil, 5-8% sl.	.49	3	5	40	65	IIe	79	
Grenada sil, 2-5% sl.	.49	3	3	45	62	IIe	77	
Center sil, 1-3% sl.	.49	5	3	45	62	IIe	77	Medium
Calloway sil, 1-3% sl.	.49	3	3	55	54	IIe	67	
Lexington sil, 5-8% sl.	.49	3	5	55	54	IVe	65	
Lexington sil, 8-12% sl.	.49	3	7	65	46	VIE	53	
Loring sil, 5-8% sl.	.49	3	5	70	42	IVe	50	
Grenada sil, 5-8% sl.	.49	3	5	7	38	IVe	45	Low
Routon sil	1/	1/	20	60	50	IIIw	45	
Loring sil, 8-12% sl.	.49	3	7	65	41	VIe	45	
Lexington sil, 12-20% sl.	.49	3	14	75	38	VIe	34	
Loring sil, 12-20 sl.	.49	3	14	75	38	VIe	29	Very low
Waverly sil, freq. fl.	1/	1/	28	70	42	IVW	27	

1/ Not applicable; not subject to erosion.

The factors used, each of which is sometimes used alone as indicators of soil conservation problems, are:

a. Factors for calculation of sheet and rill erosion for optional cropping systems for individual soils (to determine if conservation objectives are met):
   - K erodibility factor
   - T soil loss tolerance
   - LS slope length – steepness factor
b. Rainfall erosiveness factor (R).
c. Crop yield under a high level of management.
d. The kind and cost of corrective measures needed and considered to be feasible.

The integration of these factors in the soil potential analysis follows the broad outline of a cost/return analysis, and the resulting indexes are a reasonably accurate analysis of the quality of agricultural soils assuming conservation objectives are met. They do not accomplish the economic comparison of alternative approaches to farming, however, as cost/return analyses do. A recent study illustrates a detailed analyses of optional systems of conservation farming in Western Tennessee (5), and provided some of the data needed for this soil potential analysis.

A comparison to Land Capability Class and Subclass is also presented in Table 14.5. Although the sequence in general follows increasing restrictions in use (increasing capability class), there are notable exceptions. For example, soils with medium potential range from Class II to Class IV. Similarly, soils with low potential range from Class III to Class VI. Also, soils in a given land capability class are shown to have a wide range in SPI, e.g. soils in Class II range in SPI from a high of 120 to a low of 67. Land capability classes do not differentiate the productivity of soils, although the cost of overcoming limitations does have a relationship to these classes.

The soil potential analysis is thought to represent a more sensitive approach to land evaluation for conservation farming than any other approach currently in use in the United States. It differs from the typical land evaluation schemes (3) in focussing more on the effects of soil properties on needed management practices and yields than on the soil properties themselves. It emphasizes productivity and the difficulty of achieving that productivity, and includes general economic analyses important to land users.

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15 Soil potentials: an evaluation of a rating method in Zimbabwe

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15.1 Soil potential ratings

Soils have varying potentials. Given a standard set of management practices, or a single farming system, with fixed inputs to the soil, different soil types will yield differently. Not only this, some soil types may sustain high yields over time whereas others will show a marked drop in yield as erosion or worsening nutrient and soil conditions undermine the productive base of the soil.

It is with the view of describing the inherent productive characteristics of soils and their dynamics that Soil Potential Ratings (SPR) were devised by the United States Department of Agriculture as a planning tool for guiding decision-makers in determining the relative suitability of soils for a given use. The following notes on the concept of SPR are taken from an US evaluation of methodology in Richmond Country, Virginia, and Part 603 of the National Soils Handbook. The main part of the paper is an evaluation of the method on Zimbabwe data.

15.1.1 Definition of soil potential ratings

SPRs are classes that indicate the relative quality of a soil for a particular use compared with other soils in a given area. Yield or performance level, the relative cost of applying modern technology to mini-mize the effects of any soil limitations, and the adverse effects of continuing limitations, if any, on social, economic or environmental values are considered. The criteria for developing soil potential ratings for a particular use are established specifically for the area for which the ratings are made; the criteria may be different in nearby areas, regions and countries. They will almost certainly be different for various farming systems and levels of technology.

15.1.2 Purpose of soil potential ratings

Although SPRs have to date only been developed in the United States, their emphasis on local circumstances and adaptation to socio-economic conditions make them possibly applicable to a wide range of farming environments. They are not intended as specific recommendations for soil use, but are designed to be used in conjunction with other resource information as a guide to making land-use decisions. Soil Potential Ratings can be adapted to emphasize certain desirable management practices, such as the application of erosion control measures, and to put these practices into context in terms of additional costs which may offset increased production.

SPRs are intended to supplement land capability classes, suitability ratings for various purposes and other methods of assessing land uses. As a relatively simple procedure, utilizing available information and stressing local costs and problems, SPRs may be a reasonable substitute for other interpretations.
As a form of soil interpretations, SPRs:
- provide a common set of terms, applicable to all kinds of land use, for rating the quality of a soil for a particular use relative to other soils in the area;
- identify the corrective measures needed to overcome limitations and the degree to which the measures are feasible and effective;
- enable local preparation of soil interpretations, using local criteria to meet local needs;
- provide information about soils that emphasizes the feasibility of use rather than avoidance of problems;
- assemble in one place information on soils, corrective measures and the relative costs of corrective measures;
- make soil surveys and related information more applicable and easily used in resource planning; and
- strengthen the resource planning effort through more effective communication of the information provided by surveys and properly relating that information to modern (available) technologies.

15.1.3 General concept of the soil potential index

The Soil Potential Index (SPI) is a numerical rating of a soil's relative suitability or quality. Although calculated quantitatively, it is used to rank soils into qualitative categories from high to low according to their potential.
SPI is expressed by:

$$SPI = P - (CM + CL)$$

where

P = index of performance or yield as a locally established standard.
CM = index of costs of corrective measures to overcome or minimize the effects of soil limitations.
CL = index of costs resulting from continuing limitations.

All the index values are intended to be general in nature and to have no intrinsic physical meaning other than to establish relative positions of a parameter. Detailed economic analyses are inappropriate and not required. Values for CM and CL must be on the same basis: e.g. on an annual basis and both related to yields per hectare.

1. The Performance or yield standard (P) is established and defined locally. The actual yield of each soil is compared to the standard. For some soils, the yield may exceed the standard; in which case SPI is adjusted upwards to reflect the higher yield or performance for the soil. Substandard yields are incorporated as a Cntinuing Limitation (CL).

   In most situations, the standard chosen for P is above the average for an area but below that achieved on the very best soils. It could perhaps be seen as a target level of yield to which all soils suitable for cropping could aspire given enough inputs of technology.

For soils with yields less than the standard, the lower yield is considered a continuing limitation (CL) equal to a factor representing the amount the yield is below the standard. CL is therefore increased to account for the lower yield that is not overcome by corrective measures.

2. The cost of Corrective Measures (CM) is an index of added costs above a defined standard installation or management system that is commonly used if there are no soil limitations that must be overcome. For example, the extra costs incurred to install contour terraces on an erosionally-susceptible soil are accounted for in CM.
3. The cost of Continuing Limitations (CL) is an index of those limitations which necessarily continue even after corrective measures have been applied. They may be social, economic or environmental costs resulting from such diverse factors as continuing maintenance of erosion control measures to pollution.

Further details and examples of the derivation of Soil Potential Indices are given in the US National Soils Handbook.

15.2 An evaluation of SPR in Zimbabwe

The primary purpose of this paper is to see how far a methodology of soil interpretation designed and used in the United States is applicable to tropical soils and the conditions of a developing country. Clearly on both counts Zimbabwe is very different from the United States; its soils are predominantly sandy, with low reserves of available minerals and erosion problems such as surface crusting, while its human environment is strongly differentiated between the commercial sector and subsistence farming on the communal lands.

An evaluation of the SPR methodology is therefore needed on the grounds that:

- human and physical environmental conditions are very different from the USA.
- data availability is much poorer; no large banks of information on resources and yields are kept, and that information which is available is either scattered or anecdotal.
- rural land holding is in three categories:
  1. the communal lands; mainly present subsistence production with no technological inputs and often low productivity (about 45% of the country).
  2. small-scale commercial farming area (ex-Native Purchase Lands); some improved methods utilized (10%).
  3. commercial farming areas; large-scale agricultural units producing for market and utilizing tractors, chemicals and other inputs. But note that resource constraints are still more prevalent than in US (40%).

  Farming systems are correspondingly more complex and may in small-scale farming involve intricate systems of intercropping and mixed planting.
- land-use planning techniques and procedures are very different.

An immediate problem which arose in attempting to evaluate SPRs in Zimbabwe is the very different standards and methods of farming which coexist side-by-side. Prior to Independence in 1980 nearly all agricultural research and accurate data were confined to the commercial sector. The contribution of the subsistence sector was substantial in that it supported (albeit barely) some 90% of the population. Nevertheless, information on yields, costs of production, levels of technology and inputs deemed necessary for production is not only much better for the commercial sector but is also on a different basis between the sectors. For example, the main objective in subsistence production is to produce a reliable yield in any one year, whereas in commercial production it is to optimize production over a number of years. Crop varieties which will yield something under infertile droughty and poor management conditions seldom produce high yields under good conditions.

It was decided, somewhat reluctantly, to confine calculations of SPRs to commercial farming conditions because of the data availability and the fact that the countries of sub-Saharan Africa have such a precarious food security situation that at the present time can only be met by relatively large-scale production. Some comments are added at the end of this paper of the possible relevance of SPRs to small-scale and subsistence farming.

15.2.1 Evaluation area

The evaluation is based on the Karoi-Chinoyi (ex-Sinoia)-Banket group of Intensive Conservation Areas situated some 100 km north-west of Harare, the capital of Zimbabwe. The area was chosen because of its agricultural importance and the fact that soils information is fairly good. An unpublished soil survey of the whole area was carried out in 1977 using the Zimbabwe system of classification (latest edition: Thompson & Purves, 1978) which is itself a derivation of the soil map of Africa by the Inter-African Pedological Service. The Banket area also has a detailed soil survey at 1: 50,000 (Purves et al, 1981) because it was chosen as a pilot project for a National Soil Mapping programme which never materialized.

The whole evaluation area is about 9,000 km^2. Commercial farming dominates the agricultural economy and is organized into twelve Intensive Conservation Areas (ICA), an ICA being an administrative division of what formerly constituted the European farming lands. Three Purchase Lands (formerly African Purchase Lands) are also included where farming is semi-commercial to subsistence on plots of no more than 200 ha. Agriculturally the whole area is one of the most intensive in Zimbabwe, based principally on dryland cropping of maize and flue-cured tobacco with lesser quantities of cotton, soyabeans and burley tobacco. Crop yield estimates are available for the major crops by ICAs and Purchase Lands, and for this report are taken from Agritex (1982). Yields are not available by soil type: this information has had to be inferred from a knowledge of the soils within each ICA and from local expert information.

The climate is subtropical with a strongly seasonal rainfall regime giving a relatively reliable 800-850 mm mean annual rainfall. Climatic data for Banket is given in Table 15.1.

Table 15.1 Climatic data for Banket Station (17° 19' S. 30° 24' E., altitude 1,244 m) – from Purves et al., 1981.

Month	Rainfall (mm)	Raindays	24-hour mean temp. (°C)	Mean daily Max. °C	Mean daily Min. °C	Absolute Min. °C
July	0	0	15,0	23,3	7,9	3,0
August	2	0	17,2	25,7	9,9	4,3
September	5	1	20,4	29,2	12,7	5,8
October	25	3	22,6	30,7	15,8	8,1
November	96	9	22,0	28,7	16,6	11,9
December	164	14	21,2	27,0	16,7	12,8
January	215	16	21,2	26,7	16,9	13,5
February	169	14	21,0	26,6	16,6	11,0
March	93	9	20,8	27,0	15,7	8,8
April	40	4	19,4	26,3	13,8	7,2
May	9	1	17,2	24,8	10,7	3,7
June	4	1	14,7	22,6	7,9	1,7
YEAR	823	72	19,4	26,6	13,4	1,7

This pilot evaluation of Soil Potential Ratings is conducted for maize, commercially the most valuable and widespread food crop in Zimbabwe.

15.2.2 Soil evaluation

Under Zimbabwean conditions, the soil properties that need to be evaluated with respect to soil potential are:

1. Slope.
   This partly determines the erosion control practices that are to be followed. Slope is incorporated into SPI through the costs of contouring:
   Slight: 0-2% Moderate: 2-6% Severe: 6-15+%
   (Note: contouring may not be a viable option in some communal areas.)
2. Drainage class.
   On the soils considered, this is not a problem. Drainage is either adequate or cannot practically be altered. On some hydromorphic or vlei soils (Histosols), drainage is poor but cultivation is either discouraged or prevented by law because of the erosion hazard and the lowering of water table, thereby causing perennial rivers to cease in the dry season. No account is therefore taken of drainage class.
   (Note: Histosols are often used (albeit illegally) for vegetable plots in communal areas.)
3. Soil fertility.
   A major variable between soils types. Under commercial cultivation, a high level is needed, and corrective applications of fertilizer differ between the soil types. Three categories of initial fertility status are defined – good, medium, poor – according to normal nutrient levels and distribution of nutrients.
   (Note: crops are grown on soils with very low fertility levels in communal areas. The use of inorganic fertilizer is often not a viable option.)

4. Organic matter content.
   Levels are normally low and should be maintained on all soils by stubble mulching. (Note: this will not be possible in the communal areas where cattle rely on the stubble for dry season grazing.)
5. Compaction/crushing.
   This is a severe problem on some soils. Loss of structure and plough pans are common, requiring additional machiriery operators. Crusting occurs under poor covers: it reduces infiltration and causes greater drought stress.
6. Soil toxicity.
   Certain soils have toxic levels of some elements (primarily Al, Cr, Ni), either because of their natural abundance from the solid geology or acidification. The only possible corrective measure is intense liming, which is not considered a viable proposition. Hence two categories are defined:

   Non-toxic – no costs
   Toxic – no agriculture; yield level nil.

15.2.3 Corrective measures

1. Erosion control practices recommended by Agritex in Zimbabwe are:
   (a) 0-2% slope – no contouring normally necessary;
   (b) 2-6% slope – good cover crops, contouring and some small physical works such as storm waterways;
   (c) 6+% slope – contouring plus land-use planning measures (crest roads, lined waterways, diversions etc.).

For many purposes, broad-based terraces are preferable. But they are only viable on relatively smooth lands. They cost more to install but are cheaper to maintain. Planting can be over the whole land surface and hence no crop loss is involved.
Narrow-based (1.35 m) contours are more common and are the only means on complicated terrain. They are cheaper to install but expensive to maintain. Approximately 14% of the land surface is lost to cropping.
This evaluation will confine itself to narrow-based contour terraces only as the measure most likely to be used in the area.
The costs of erosion control are based on three assumptions:
1. the land has been previously cultivated;
2. fuel efficiency is 70%;
3. the power source is a 56 kw tractor; cut width 0.8 m; speed 6.4 km/h. (Note: if calculations were to be based on draught power by oxen under average Zimbabwean conditions, one hectare would take 8.7 hour to plough with the first rains. With a hoe or badza, 20 metres of contour per labour-day is normal, or about 5 man-days per hectare.

Narrow-based contours with four runs of 3-furrow mounted disc plough and four runs of a contour ridger for construction will require 2.96 litres of fuel per 100 m contour and 17 minutes tractor time per 100 m. Fuel price is 0.96 cents/litre.

The spacing of contour terraces is calculated according to slope and soil erodibility; the more erodible the soil, the closer is the terrace spacing for any one slope. Design values according to the erodibility indices currently in use in Zimbabwe have already been calculated – see Table 15.1, p. DP21 in Elwell (1980). Adapting this information according to costs of contour construction and the three grades of slope being used in this paper.

Slope category %	Length of narrow-based contour required (Metres/ha)			
	Erodibility factor			
	3	4	5	6
0-2	260	215	185	160
2-6	370	320	290	260
6+	500	465	435	410

This is the F_b – value in the Soil Loss Model for Southern Africa. Low F_b – values indicate high erodibility.

Therefore, from known costs of running machinery for contour construction:

Slope category %	Increased machinery costs (Z$ per ha)*			
	Erodibility factor			
	3	4	5	6
0-2**	10	9	7	6
2-6	15	13	12	10
6+	20	19	17	16

* Increased machinery cost is calculated as the cost of the contour ridger runs alone; i.e. half total machinery costs.
** In practice, these contours would not be constructed except in the case of a very poor cover crop. Therefore, use zero cost for normal application.

In addition to the above:

on 2-6% slope	construction of storm waterways etc.	Z$ 10/ha
on 6+% slope	construction of diversions, lined waterways etc.	Z$ 20/ha

2. Soil Fertility.
Cost of bringing up to a 75% yield level (i.e. a percentage yield level of maximum obtainable on research stations achievable by good farmers under real farming conditions). Three categories of initial fertility status.
Basic cost of fertilizer whether supplied as a compound NPK or in individual components is Z$ 260/tonne (1984 prices, based on actual cost of Compound X, 20:10:5).

Initial fertility status	Cost of fertilizer requirement for commercial level (Z$/ha)	Additional cost of bringing up to good level
good soils	47	nil
medium soils	73	26
poor soils	94	47

3. Compaction/crusting.

Additional cost of ameliorating soil conditions through subsoiling, chisel ploughing and mulching. Three grades of physical problems are identified:

		Additional cost per hectare
No problem	– normal management is sufficient	0
Moderate	– additional mulching and some subsoiling	$ 5
Severe	– rotational tillage, including zero, minimum, chisel and conventional, plus mulching	$ 10

15.2.4 Corrective measure index

$$\text{CM Index} = \frac{\text{Annual cost of measure per hectare cropped land}}{\text{Producer price for maize in \$ per kg}}$$

For the 1984/1985 season the declared producer price for maize is Z$ 180/tonne. To give the CM Index greater meaning it can be thought of as an equivalent measure of yields per hectare:

$$\text{CM Index} = \frac{1000}{180} \text{ x costs per hectare (kg/ha)}$$

Hence (index rounded to nearest 5 kg/ha):

Costs per hectare	CM (kg/ha)
$ 1	5
5	30
10	55
20	110
50	280
100	555
180	1000

The index value for the various corrective measures is:

A. Erosion control practices.

Slope	CM Index			
	Erodibility factor			
	3	4	5	6
0-2%	–	–	–	–
2-6%	85	75	65	55
6+%	110	105	95	90

PLUS	2-6% slopes	Storm waterways etc.	CM Index = 55
	6+ % slopes	Diversions, waterways	CM Index = 110

B. Soil fertility.

Initial fertility	CM Index
good	–
medium	145
poor	260

C. Compaction/crusting.

Status	CM Index
No problem	–
Moderate	30
Severe	55

15.2.5 Continuing limitations (CL) index

The corrective measures require annual maintenance and/or continuing inputs. These are locally determined upon the best available advice. For the study area, they have been taken as:

Measure	Action	CL Index
A. Narrowbased contour terrace.	Maintenance at one-half initial corrective measure.	See basic CM – values for erosion control practices and divide by two.
	PLUS	
	Cost of reduced planting area.	14% of Performance Standard Index.
B. Soil fertility	Maintenance of fertility by continuing inputs.	Half basic CM – values.
	PLUS	
	Special circumstances, including; * additional drought through reduction in organic matter levels.	CL index assigned according to estimated yield loss through limitation.
	* toxic patches in field.	
C. Compaction/ crusting (severe soils only)	Additional machinery cost for chisel ploughing every 3 years.	30

15.2.6 Calculation of soil potential index (SPI)

The soils of the Karoi-Chinoyi-Banket area are briefly described on the worksheets presented as Appendix I of this paper.

Because crop yield data are not directly related to specific soil types, soil type-yield values were inferred from ICA and Purchase Land crop yields, the known distributions of soil types and field experience. Some yield data are shown in Table 15.2. Although in this area the soils are not markedly different on the Purchase Lands, the yield difference between the commercial farming on ICAs and semi-subsistence/commercial farming on Purchase Lands should be noted.

Table 15.2 Crop yield data by Intensive Conservation Area and Purchase Lands in the Karoi-Chinoyi-Banket group of ICAs. Yield refers to 3-year average of long season dryland maize (Agritex, 1982).

Area	Average yield (kg/ha)	Dominant soil groups
ICAs		
Karoi North	4814	all 5P
Karoi Central	5071	mainly 5G; some 5F and 5P
Karoi South	4233	all 5F
Tengwe	4247	5G and 5F
Doma	5088	Mixture: 5G, 5F, 5S, 5E, 4E, 5A
Angwa North	5437	5S, 5A, 5M
Angwa South	4788	5F, 5S, 5G, 5M
Ayrshire North	4115	5G, some 4E
Ayrshire South	4400	nearly all 5G; band of 3X/5X
Banket-Eldorado	5085	5G, 5A, 4E
Trelawney	4412	5G
Darwendale	4535	nearly all 5G
Purchase Lands		
Vulti	3097	–
Chitomborgwizi W.	1889	–
Nyakapupu	2057	–
Average for ICAS in Mashonoland North	4650	–
Average for Purchase Lands in Mashonoland North	2165	–

For the purposes of this evaluation the following yield levels for maize according to soil type are taken (based on commercial farming practice).

Soil type	Yield
3X	3200
5X	3200
5M	4000
4E	4100
5F	4200
5G	4700
5P	4800
5A	5000
5S	5000
5E	5200

Table 15.3 collates and summarizes all the information and data presented in this paper and on the worksheets in Appendix I.

Table 15.3 Soil Potential Index Rating and yields for maize, in Caroi-Chinoyi-Banket area of Zimbabwe.

Soil type*	Soil Potential Index		Rating	Estimated yield kg/ha
	Index	Index, base 100**		
5E	5170	103	Very High	5200
5P	4140	83	Medium	4800
5F	4075	82	Medium	4200
5S	4055	81	Medium	5000
4E	3950	79	Medium	4100
5M	3890	78	Medium	4000
5G	3285	66	Low	4700
5A	3225	65	Low	5000
3X	2000	40	Very Low	3200
5X	1905	38	Very Low	3200

* See Appendix I for soil series descriptions.
** Index, 100 = Performance Standard Index, 5,000.

15.3 Conclusion

The Soil Potential Rating Method has been applied to an area of Zimbabwe for commercial maize farming. It has provided a rating of soil types according to standard yields and the cost and difficulty of obtaining those yields, provided that certain basic management precautions are taken to maintain the fertility and the sustainability of production on these soils.

As can be seen from Table 15.3, the Soil Potential Index expresses more than simply the estimated yield under normal farming practice. The only soil rated 'very high' or 'high' is the most fertile and highly-prized soil of the area. However, the extensive 5G soil (granite-derived), which is used for maize cropping by most farmers and on which estimated yields are about 4,700 kg/ha, is rated only 'low' because of the cost and difficulty of managing the soil satisfactorily. Similarly, other soil types are rated to differing degrees below their estimated yield levels, such that although cropping is possible on 3X and 5X soils, it would be economically and environmentally foolhardy to attempt it.

In concept, the Soil Potential Rating method as used in this evaluation is identical to that employed by the United States Department of Agriculture. The method has had to be adapted for use on tropical soils, and the calculations altered to use kg/ha as the index and yield measure.

Several salient points arise as to the application of Soil Potential Ratings in a developing country and on tropical soils:

1. The method does need adaptation for the more critical use limitations of tropical soils. In particular the USDA methodology for Richmond County specifies that

as a high level of fertility is needed on all soils, no detectable difference in fertility status was noted. This would certainly not be the case for tropical soils which not only have widely-varying nutrient status but also suffer nutrient imbalances and toxicities which are absolutely crucial to both management and yields. These considerations need further examination.

2. It is worth emphasizing the critical nature and levels of organic matter in soils which affect nutrient status and water capacity. This may need separate consideration in any future development of SPRs.
3. Drainage receives emphasis in the USDA study, but would be comparatively less important under rainfed cropping in the seasonal wet-and-dry tropics.
4. Erosion is dealt with in the SPR methodology by assigning an index relative to the cost of constructing and maintaining terraces for erosion control. This implies that contour (or gradient) terracing is the favoured means of soil and water conservation. Throughout the tropics it is now becoming accepted that terracing or other forms of physical conservation are only secondary lines of defence; more effective against raindrop detachment and overland transport are the types of tillage and cropping practices. Mulching, intercropping, contour ridging, tied ridging amongst many others are now receiving greater emphasis. Perhaps the most appropriate role for terraces and the construction of physical conservation works is in commercial farming where machinery is available and within-field uniformity is desirable....but it may not be appropriate for other farming systems.
5. Many of the most critical soil degradation problems in the tropics occur on small, subsistence farms. Any SPR methodology applied to these farming systems would have to be extensively revised to take account of:
   - different levels of technology;
   - different degrees of appropriateness of technical solutions;
   - non-economic benefits, such as lessening of risk and uncertainty;
   - the requirements for a wide range of crops and land use on any one farm.

   Such revision of SPR methodology has not been attempted in this paper, but should have urgent priority if the method is to be applied to developing country conditions. For many countries dual (or triple?) standards may need to be developed. The emphasis in the present US use of SPRs towards technical solutions to limitations would have to be modified because of the unavailability of fuel, tractors, spares or technical expertise.
6. SPRs have a minimum requirement of data availability; generally, soils information to the series level and crop yields. Only about 7% of Zimbabwe has this soils information and other countries might be in a worse position. Therefore, either more mapping and data are needed or very experienced local staff must be involved.

In the final analysis, Soil Potential Ratings appear to be a most useful planning tool in integrating the many strands affecting the use and sustainability of a soil. For any given farming system and level of technology SPRs can be locally derived reasonably quickly by an experienced soil scientist with crop yield data and local experience. It is recommended that Soil Potential Ratings be further developed and applied to development projects as a valuable way of bringing together soils information, the economic cost of managing a soil effectively, economic returns to the farmer and, in the future, the overall social and economic benefits of developing agriculture on one soil type vis a vis another.

PROFORMA WORKSHEET FOR PREPARING SOIL POTENTIAL RATINGS

Soil Use: MAIZE

Area: KAROI-CHINOYI-BANKET, ZIMBABWE

Soil Mapping Unit: 5E

Description: Fersiallitic group; moderately deep to deep, reddish brown granular clay; formed on mafic rocks. Erodibility, $F_b = 60$ [Banket 5E = chromic cambised (FAO/UNESCO) or Rhodic Paleustalf (Soil Taxonomy)]

Expected yield level under current farming system: 5200 Kg/ha

Evaluation factors	Site conditions	Degree of limitation	Effects on use	Corrective Measures		Continuing Limitations	
				Kind	Index	Kind	Index
SOIL LIMITATIONS							
Fertility	Most are inherently fertile. Rooting depth > 70 cm.						
Compaction/crusting	Locally a problem	moderate	affects emergence and infiltration	mulching + correct tillage	30	—	
SLOPE	Seldom exceeds 2 %	none (broad-base terraces on steeper sites)					

TOTAL: 30 TOTAL:

5000 − 30 − 0 = 4970 + 200* = 5170

Performance Standard Index	Measure Cost Index	Continuing Limitation Index	SOIL POTENTIAL INDEX
5000	30	0	4970 + 200* = 5170

(*Note: if performance exceeds the standard increase SPI by that amount)

PROFORMA WORKSHEET FOR PREPARING SOIL POTENTIAL RATINGS

Soil Use: MAIZE

Area: KAROI-CHINOYI-BANKET, ZIMBABWE

Soil Mapping Unit: 5P

Description: Fersiallitic group; variable depth, brown to reddish brown, fine to medium grained sandy Loam, over sandy clay Loam; formed on siliceous gneiss. Erodibility $F_b = 4$

Expected yield level under current farming system: 4800 Kg/ha

Evaluation factors	Site conditions	Degree of limitation	Effects on use	Corrective Measures		Continuing Limitations	
				Kind	Index	Kind	Index
SOIL LIMITATIONS							
Fertility	good	–					
Compaction/crusting	problem under poor cover	moderate	water stress + seed emergence problems	Appropriate tillage	30	–	
SLOPE	undulating terrain 2-6% slope	moderate - esp. with high erodibility	erosion risk	erosion control practices	75 + 55	Maintenance of contours	30
						Reduced planting area	670
				TOTAL:	160	TOTAL:	700

5000	–	160	–	700	=	4140
Performance Standard Index		Measure Cost Index		Continuing Limitation Index		SOIL POTENTIAL INDEX

(*Note: if performance exceeds the standard increase SPI by that amount)

PROFORMA WORKSHEET FOR PREPARING SOIL POTENTIAL RATINGS

Soil Use: MAIZE

Area: KAROI-CHINOYI-BANKET, ZIMBABWE

Soil Mapping Unit: 5 F

Description: Fersiallitic group; shallow, reddish-brown; highly micaceous, fine sandy loam over sandy clay loam; formed on micaceous materials. Erodibility $F_b = 5$

Expected yield level under current farming system: 4200 kg/ha

Evaluation factors	Site conditions	Degree of limitation	Effects on use	Corrective Measures		Continuing Limitations	
				Kind	Index	Kind	Index
SOIL LIMITATIONS							
Fertility	shallow soil	medium	drought stress	mulching + add. fertilizer costs	145	Continuing drought stress - est. 15% yield loss	630
SLOPE	3% average	medium category	some erosion risk	erosion control practices	65 + 55	Maintenance of contours [Note: normally broad-base because of smooth slopes no loss in planting area]	30
				TOTAL:	265	TOTAL:	660

5000 − 265 − 660 = 4075

Performance Standard Index		Measure Cost Index		Continuing Limitation Index		SOIL POTENTIAL INDEX
5000	−	265	−	660	=	4075

(*Note: if performance exceeds the standard increase SPI by that amount)

PROFORMA WORKSHEET FOR PREPARING SOIL POTENTIAL RATINGS

Soil Use: MAIZE

Soil Mapping Unit: 5S

Expected yield level under current farming system: 5000 kg/ha

Area: KAROI-CHINOYI-BANKET, ZIMBABWE

Description: Fersiallitic group; variable depth, reddish brown to grey-brown silty clay loams over clay; formed on argillaceous sediments.

Erodibility $F_b = 4$

Evaluation factors	Site conditions	Degree of limitation	Effects on use	Corrective Measures		Continuing Limitations	
				Kind	Index	Kind	Index
SOIL LIMITATIONS							
Fertility	good	–					
Compaction/ crusting	generalised problem	severe	drought stress + tillage problems	tillage, mulching inc. chisel	55	continuing cost	30
SLOPE	5% average	moderate — esp. with high erodibility	erosion risk	erosion control practices	75 + 55	Maintenance of contours reduced planting area	30 700
				TOTAL:	185	TOTAL:	760

5000	–	185	–	760	=	4055
Performance Standard Index		Measure Cost Index		Continuing Limitation Index		SOIL POTENTIAL INDEX

(*Note: if performance exceeds the standard increase SPI by that amount)

PROFORMA WORKSHEET FOR PREPARING SOIL POTENTIAL RATINGS

Soil Use: MAIZE

Area: KAROI-CHINOYI-BANKET, ZIMBABWE

Soil Mapping Unit: 4A

Description: Siallitic group; shallow to moderately-shallow, brown or reddish brown clays, formed on mafic rocks. Erodibility $F_b = 4$ [Banket 4E = Gleyic Phaeozem (FAO/UNESCO) or Typic Tropudalf (Soil Taxonomy)]

Expected yield level under current farming system: 4100 kg/ha

Evaluation factors	Site conditions	Degree of limitation	Effects on use	Corrective Measures		Continuing Limitations	
				Kind	Index	Kind	Index
SOIL LIMITATIONS							
Fertility	shallow, but fair nutrient levels & water holding	moderate	need for fertilizer + protection from nutrient leaching	fertilization	145	continuing cost	70
SLOPE	slope > 6%	Severe - esp. with high erodibility	Careful management for erosion risk	erosion control practices	105 + 110	maintenance of contours	50
						reduced planting area	570
				TOTAL:	360	TOTAL:	690

5000 (Performance Standard Index) − 360 (Measure Cost Index) − 690 (Continuing Limitation Index) = 3950 (SOIL POTENTIAL INDEX)

(*Note: if performance exceeds the standard increase SPI by that amount)

PROFORMA WORKSHEET FOR PREPARING SOIL POTENTIAL RATINGS

Soil Use: MAIZE

Soil Mapping Unit: 5 M

Expected yield level under current farming system: 4000 kg/ha

Area: KAROI-CHINOYI-BANKET, ZIMBABWE

Description: Fersiallitic group; variable depth, greyish brown sands or Loamy sand over sand Looms; formed on sandstones and quartzites of Triassic formations.
Erodibility $F_b = 4.5$

Evaluation factors	Site conditions	Degree of limitation	Effects on use	Corrective Measures		Continuing Limitations	
				Kind	Index	Kind	Index
SOIL LIMITATIONS Fertility	inherently infertile	poor	Low nutrient availability; Low water retention	fertilization	260	Continuing cost	130
SLOPE erosion hazard	slopes 1-3%	requirement for water conservation	erosion risk + drought stress	erosion control practices	70 + 55	maintenance reduced planting area	35 560

TOTAL: 385 TOTAL: 725

5000	−	385	−	725	=	3890
Performance Standard Index		Measure Cost Index		Continuing Limitation Index		SOIL POTENTIAL INDEX

(*Note: if performance exceeds the standard increase SPI by that amount)

PROFORMA WORKSHEET FOR PREPARING SOIL POTENTIAL RATINGS

Soil Use: MAIZE

Area: KAROI-CHINOYI-BANKET, ZIMBABWE

Soil Mapping Unit: 5 G

Description: Fersiallitic group; moderately shallow, greyish-brown, coarse-grained sands throughout the profile, to siltil or sandy loams over reddish-brown sandy clay loam; formed on granite. Erodibility $F_b = 4$ [Banket 5G = Ferralic Cambisol (FAO/UNESCO) or Oxic Ustropept (Soil Taxonomy)]

Expected yield level under current farming system:

Evaluation factors	Site conditions	Degree of limitation	Effects on use	Corrective Measures		Continuing Limitations	
				Kind	Index	Kind	Index
SOIL LIMITATIONS							
Fertility	shallow, 25-80cm effective rooting depth + low fertility	poor	reduced yields by drought stress + nutrient deficiency	fertilization	260	maintenance of fertility levels	130
Compaction/crusting	Locally	moderate	–	mulching + tillage	36	estimated yield loss by water deficiencies	470
SLOPE	undulating; up to 5%	medium - esp. with high erodibility	erosion risk	erosion control practices	75 + 55	maintenance of contours	35
						reduced planting area	660
				TOTAL:	420	TOTAL:	1295

[Note: 5G soils can be variable. The deeper series with more clay give class B arable land]

5000	–	420	–	1295	=	3285
Performance Standard Index		Measure Cost Index		Continuing Limitation Index		SOIL POTENTIAL INDEX

(*Note: if performance exceeds the standard increase SPI by that amount)

PROFORMA WORKSHEET FOR PREPARING SOIL POTENTIAL RATINGS

Soil Use: MAIZE

Area: KAROI-CHINOYI-BANKET, ZIMBABWE

Soil Mapping Unit: 5A

Description: Fersiallitic group; moderately shallow, greyish brown, relatively silty sandy loam over yellow sandy clay loam; formed on arenaceous sediments.

Expected yield level under current farming system: 5000 kg/ha

Erodibility, $F_b = 3.5$ [Chinoyi 5A = gleyic Cambisol (FAO/UNESCO) or Aquic Ustorthent (Soil Taxonomy)]

Evaluation factors	Site conditions	Degree of limitation	Effects on use	Corrective Measures		Continuing Limitations	
				Kind	Index	Kind	Index
SOIL LIMITATIONS							
Fertility	depth to gravel sometimes only 30 cm. moderate nutrient status	moderate	nutrient and water stress	fertilization	145	continuing cost poor nutrient availability – 10% yield reduction	70 500
Compaction/crusting	–	V. severe	Limitation on use for cropping	tillage + mulching	55	chisel plough every 3 years	30
SLOPE							
Erosion hazard	undulating slopes 1-3%	Severe erosion problems despite slopes low!	erosion risk	erosion control practices	110 + 110	maintenance of contours reduced planting area	55 700
				TOTAL:	420	TOTAL:	1355

5000	–	420	–	1355	=	3225
Performance Standard Index		Measure Cost Index		Continuing Limitation Index		SOIL POTENTIAL INDEX

(*Note: if performance exceeds the standard increase SPI by that amount)

PROFORMA WORKSHEET FOR PREPARING SOIL POTENTIAL RATINGS

Soil Use: MAIZE

Area: KAROI-CHINOYI-BANKET, ZIMBABWE

Soil Mapping Unit: 3X

Description: Vertisol group; dark brown to black but with inverse Ca/Mg ratio and often toxic quantities of heavy metals (Ni + Cr)
Erodibility $F_b = 5$

Expected yield level under current farming system: 3200 Kg/ha

Evaluation factors	Site conditions	Degree of limitation	Effects on use	Corrective Measures		Continuing Limitations	
				Kind	Index	Kind	Index
SOIL LIMITATIONS Fertility	-	toxicity problems (Cr, Ni)	almost total yield loss in some years	none	-	est. 60% loss of performance yield	3000
SLOPE	Low catenal position	slight	-				

TOTAL:

TOTAL: 3000

5000	-	0	-	3000	2000
Performance Standard Index		Measure Cost Index		Continuing Limitation Index	SOIL POTENTIAL INDEX

(*Note: if performance exceeds the standard increase SPI by that amount)

PROFORMA WORKSHEET FOR PREPARING SOIL POTENTIAL RATINGS

Soil Use: MAIZE

Area: KAROI-CHINOYI-BANKET, ZIMBABWE

Soil Mapping Unit: 5 X

Description: Fersiallitic group; moderately deep clays similar to 5E, but with inverse Ca/Mg ratios and often toxic heavy metals (Ni, Cr); formed on ultrabasic rocks.

Erodibility, F_b =

Expected yield level under current farming system: 3200 Kg/ha

Evaluation factors	Site conditions	Degree of limitation	Effects on use	Corrective Measures		Continuing Limitations	
				Kind	Index	Kind	Index
SOIL LIMITATIONS Fertility		toxic patches	almost total loss of production in some years	none	–	est. 50% loss in performance yield	2500
SLOPE	2-6% midslope	moderate	erosion risk	erosion control practices	55 + 55	maintenance of contours reduced planting area	35 450

TOTAL: 110 TOTAL: 2985

5000	–	110	–	2985	=	1905
Performance Standard Index		Measure Cost Index		Continuing Limitation Index		SOIL POTENTIAL INDEX

(*Note: if performance exceeds the standard increase SPI by that amount)

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Discussion

Dudal: For the study in the United States an extensive reference base was available; what to do in developing countries where you do not have these benchmark sites?
McCormack: In many cases crop requirements are known and crop data are available; if no yield data are available then we must return to the relationship between single soil properties and crop yield; the disadvantage is that the interactions are so difficult.
Driessen: Information requirements are needed; the backside of an envelope may be seen as the predecessor of the computer.

Bennema: How does the FAO Framework fit in the described procedure?
McCormack: We participated in the development of the FAO Framework beyond 1972 and feel that the approach is not so different from the one used to determine the soil potential index; there certainly was/is an exchange of ideas.

P-Hernandez: There are considerable differences between the economics of Zimbabwe and the United States; how was this problem solved?
Stocking: No subtle economic background was used; in Zimbabwe we used the actual cost of doing an (farm) operation, the prices received for crops and produce and other available data.
P-Hernandez: In subsistence agriculture there is no common unit of exchange.

van Mourik: The micro-computer has many advantages also, or in particular, for use in the field to store the information obtained; often information is lost or has to be regathered, but when using a computer this may be prevented.
Stocking: During the study emphasis was on the utilization of local knowledge using experience and common sense; I am of the opinion that the computer has no common sense; a simple method is needed and the method is to be made visible; on local scale the use of a computer is not recommended but on a national scale, yes.
McCormack: If prices and cost vary but practices and approaches are the same, one can recomputer the indexes by computer.

van Vliet: What size of area is considered and how local is local?
McCormack: When a farmer assesses his land as what to grow he is in fact carrying out a land evaluation; thus the minimum size of an area is a local farm; for land-use planning the SPI (Soil Potential Index) is best used for a town, a township or a country,

but the method could also be used for a state; however, it has most value when used locally.

Bennema: What a farmer gets for his products may be strongly variable from year to year; what is needed is a data base of an area independent of prices and costs.
McCormack: Economics must be involved to make a best general analysis of land suitability.
Purnell: This session has presented us with three sets of models:
- one model predicting erosion
- one model computing land productivity on a large scale
- one model of pricing soils according to their potentials; especially the last model posed the question of 'can new agrotechnology be transferred from a developed country to a developing country,' and the answer is 'yes'.

16 Methods of elaborating projects on the utilization and conservation of mountainous territories

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Studying and designing are a complex of purposeful activities aimed at elaborating a system of analyses, models, diagrams, drafts, technical and economic calculations and indices for determining the technical feasibility and economical advisability or benefit of the undertakings, reconstruction and broadening of the existing building projects or initiating new ones aimed at the development of the territories and the human settlements in accordance with the integrated planning of the social and economic development of the country (1).

Designing activity in the People's Republic of Bulgaria is carried out by a number of specialized institutes and organizations at the respective ministries.

Designing activity in the field of agriculture is conducted mainly by two organizations – Agropromproject' and 'Vodproject'. The research institutes also take an active part in designing activities mainly in the form of consulting, publishing guides, instructions and model designs, issuing parameters and indices as a result of their research work, introducing foreign top experience into practice, presenting new technological solutions, etc.

The elaborated designs are accepted and certified by an expert committee, consisting of the most outstanding specialists in the respective field. After being certified, they are executed by specialized building organizations, these disposing of appropriate equipment, or by the organizations for whom the designs are prepared.

Normally, designing proceeds in two phases:

1. Preparing a technical-economic report;
2. Elaborating an executive design.

The technical-economic report on the rational utilization and conservation of the ecosystems in the semi-mountainous and mountainous regions consists of several parts.

16.1 Considerations, aim and legalization

This part contains all juridical and other documents for the legalization of the project: technical-economic assignment with which the investor entrusts the designing of the project to the respective organization, agreement letters and contracts with other organizations which will conduct activities with the execution of the project and the elaboration of the design, protocoles from sitting, etc.

16.2 Ecological and economic characteristics of the project and analysis of the existing conditions

This part contains descriptions, tables, maps, drafts and diagrams in a suitable form, constituting the needed information presented in the following sequence:

16.2.1 Location, boundaries, area of the project site

The location of the project site is indicated on an adequate 1: 100,000, scale map. The physical-geographical region, district, settlement, water-collecting area are indicated on the map. The boundaries of the project site are studied and the adjacent economic and administrative units are marked. The natural boundaries used (watershed, river, road, etc.) are indicated and the sectors where it is advisable to modify the boundaries are shown. The distribution of the land by land users and the type of land are presented in tabular form.

16.2.2 Climatic characteristics

A description of the climatic zone, subzone and region from the climatic atlas of the country where the project site is found is made, along with their respective characteristics. The nearest meteorological stations and since when do they conduct observations are indicated. The suitability of the information for the designing is analyzed. It is processed and presented in a tabular form. The main climatic elements are:

a. Precipitations – quantity, intensity and duration of individual precipitation monthly and annually; availability of precipitation with a specific intensity and quantity. The P factor value is calculated by applying the general equation according to the N. Onchov method (2), and by using the P. Gorbachov formula for estimating the 'meteorological power' of the rains, but with other value expressions, such as

$$R = \frac{P}{t}$$

where

R is the erosion factor of the rain;
P is the rain quantity 9.5 mm; with an intensity of 0.180 mm/min;
t is the time duration of the rain with a quantity of 9.5 mm and an intensity of 0.180 mm/min.

b. Temperature – highest, lowest and mean annual air temperatures, latest and earliest frost date, duration of the frost.
c. Wind – mean annual velocity of the winds, frequency of winds in excess of 5 m/sec, diagram showing the direction and velocity of winds.

16.2.3 Relief

Geomorphological characteristics of the region are elaborated. More important relief forms, such as mountains, slopes, ridges, plateaus, valleys, river terraces and others are described. A map of the inclines and a map on a 1:10,000 scale of the exposure are drawn. The length of the effluent lines on areas with similar inclines are measured. The information from these maps is summarized in respective tables.
Information on the horizontal and vertical branching of the relief is given.
The LS factor is calculated using a general equation.

16.2.4 Hydrological and hydrographical characteristics

A map of the water-collecting area is prepared on a 1:10,000 scale. The morphometric characteristics of these areas are presented in a tabular form.

On the map of the water-collecting areas, with a red line are indicated the parts of the water streams with an active lateral and in depth subversion, and with a green line those with only lateral subversion. The screes, landslides, significant water sources, ponds and the others of the kind are also indicated.

Information is given on the water streams – permanent, casual, torrental; capacity of the water sources; level and characteristics of the underground water and its effluent.

16.2.5 Soil characteristics

A soil map is drawn on a 1:10,000 scale, accompanied by information from the soil report, and containing the K-factor (susceptibility to soil erosion) values.

16.2.6 Geobotanical characteristics

It contains information on the forest, bush and grass growth, on vegetation zones, their location, forest reserves, agricultural crops grown. The C-factor (soil protective ability of the vegetation) values are also given.

16.2.7 Erosion characteristics

A map is drawn on the intensity of the potential erosion and a map on the intensity of the actual area affected by water erosion.
The calculation of the soil losses is conducted with the general equation: A = RKLSCP.
The information on soil erosion is given in a tabular form.

16.2.8 Land resources and their use

A cadastral map on a 1:10,000 scale is drawn, the boundaries of the individual land forms indicated, as well as the varieties of crops drawn in different colours, the existing territorial organization (crop rotation, perennial plantations, pastures, forests); the meliorative measures conducted – irrigation, drainage, cleaning, etc. The respective areas are indicated with boundary lines and the more significant facilities are shown. The same map shows the road network, farm yards, farms, summer camps and other elements of the territorial infrastructure.

A map is drawn of the land classes in conformity with an eight degree classification, to be used effectively with the erosion control.

A summarized cadastral information, information on crop varieties by land classes, forestry and others of the kind are presented in tabular form.

An analysis is made of the information collected on the land resources and their use.

16.2.9 Economic conditions

Agriculture.

Plant growing: structure of the crops, technologies of cultivation, yields, total production, net production, net income.

Animal rearing: kind and number of the animals, structure of the herds, productivity, economic effectivity, technologies of rearing.

Basic funds: production buildings, machines, equipment, transport vehicles, meliorative measures, etc. Basic funds per 100 ha cultivated land, per animal head, per operator working in the production cycle.

16.3 Draft on the organization of the economic activity

16.3.1 Plant Growing

Planned structure of the crops. Most recent technologies for growing the crops. Needed machines for full mechanization, fertilizers, chemicals, planting materials. Expected yields with the introduction of new technologies. Planning total production, net production, net income.
Labour organization.

16.3.2 Animal rearing

Planned structure of the herds. Technologies of rearing, needed machines, forage balance, planned productivity, total production, net production, net income.

16.3.3 Forestry

16.3.4 Other economic activities

16.4 Building

The locations of all building sites – residential houses, huts, farms, shelters, penthouses are indicated on the 1:10,000 scale map.
The needed plans and documents (required by the Regulations on capital investment in building) are presented.

16.5 Roads

All existing roads which will be preserved are shown on the design. With red broken line on one side of the existing roads are shown the sectors where they will be reconstructed. With an unbroken red line are shown the new perspective roads.

All significant road facilities which will be built are also indicated.
Considerations on the necessity of constructing new roads and the improvement of the existing ones are indicated in the explanatory notes, mentioning the sites which they will serve, the traffic load, etc.

The parametres of the road overlays and designs on the cross-section profiles and road facilities are given. Quantitaties of excavation, earthfill and building work are indicated.

16.6 Disposition and organization of the cultivated crops and forests.

16.6.1 Transformation and disposition of the cultivated crops

Transformation and disposition of the cultivated crops. A table for the transformation is elaborated. The advisability of transformation of one crop into another is explained, the eight-degree classification on land suitability being used for the purpose. Legal documents for transferring land from one fund to another are presented.
The transformations are indicated on the 1: 10,000 scale map.
The suitability of the territorial disposition of the individual cultivated crops is stressed in the explanatory notes.

16.6.2 Organization of the territory of the fields

Expedient crop rotations are elaborated. The type, area, number of fields and their measurements are given in tables. Crop-rotation boundaries, boundaries of individual fields and agrotechnical plots in them are indicated. Individual crop rotations are indicated with separate colours. The number and area of the fields are given. Characteristics of the crop rotations, the fields and agrotechnical plots by land classes, soil indices, form, cultivation length and direction of the cultivated slopes is given in the explanatory notes.

16.6.3 Organization of the territory and the perennial plantations

Possible organizational-territorial changes in the existing perennial plantations are described. Variety and type, area and characteristic indices are indicated for the new plantation massifs, sectors and plots. Type of plantation, boundaries of the massifs and sectors, number and area of the plots are shown on the plan. The suitability of the type content and organization applied is stressed in the explanatory notes, this being aided by the available information and the ecological and economic characteristics. Important indices in this respect are suitability of the soil and the climatic conditions, and classes, bonitetic and economic assessment, characteristics of the sectors depending on the relief, exposure, form, etc. Compatibility of the linear elements (roads headlands for turning the machines, paths for taking out the produce, crop rows, etc.) with the relief is stressed.

16.6.4 Organizing the territory of the leys and pastures

The boundaries of the grazing complexes, the individual sectors and plots for consecutive grazing are indicated on the plan. The number and area of the complexes and herd plots are shown. With proper colouring (preferably with shades of a single colour) are the individual pasture complexes distinguished. The entries and exits for the animals and roads are indicated.

The explanatory notes contain calculations and considerations on the suitability of the herd sector sizes, number, area and form of the plots. Characteristics of the plots and their boundaries, as well as the entries and exits with respect to the relief is given.

16.7 Meliorative measures

16.7.1 Irrigation

The irrigated land, water sources, main irrigation network and important facilities are indicated on the plan. The types of irrigation – by gravity, spraying or dripping are also indicated. Considerations of this particular measure, dimensions of the irrigation network, regime of irrigation, building work and materials, detailed drafts and important facilities are stressed in the explanation notes.

16.7.2 Drainage

The areas being drained and the technology of applying this measure – through open or underground drainage systems, through deepening, levelling, or in a combined manner, are indicated on the plan.

The water collectors and important facilities are shown. The necessity of drainage is considered in the explanatory notes, accompanied by description of the technology of execution. The dimensions of the facilities and detailed drafts on the important ones are given. Needed materials and building operations are specified.

16.7.3 Meliorative measures on acidic soils

These are being indicated on the plan and the type of meliorative work – lime or phosphorus treatment, is indicated. Considerations for conducting this specific measure and the technology of its carrying-out are given. The needed materials are specified.

16.7.4 Meliorative measures on salinated soils

The areas are drawn on the plan and the type of meliorative work is indicated – chemical, biological, deep drainage, levelling, etc. Considerations for the necessity of conducting the measures, technology of their carrying-out and needed materials are specified.

16.7.5 Recultivation

The specific areas are drawn on the plan and the type of meliorative work is indicated. The explanatory notes contain considerations on the necessity of the measure, the technology of its execution and the methods of utilizing the areas after recultivation. The volume of the needed materials and the sources for their supply are given.
Excavation, embankment and transporting work are stressed.

16.7.6 Removing stones, bushes, fern and others

The areas are indicated on the plan.
The technology of conducting this measure, the needed machines, chemicals and other materials are stressed in the explanatory notes.

16.7.7 Afforestation

The areas are indicated, the technologies are described and the needed planting materials by type and quantity are shown.

16.7.8 Grass coverage

The specific areas are indicated. The technologies are described and the best grass mixtures are given. The needed seeds, fertilizers and herbicides are specified.

16.8 Erosion control measures

The type of control measures is indicated on the plan.
The explanatory notes elucidate the measures for erosion control in conformity with the general equation on the individual plan, agrotechnical sector, district or plot with perennial plantations and plot for consecutive grazing of the pesture complexes.

The technology of execution, the needed machines and the volume of work are specified for the agrotechnical measures on the erosion control.

For the engineering-technical measures on cultivated land, such as channels-terraces on a broad foundation, masonry terraces, ploughed terraces, grass-grown ones or underground effluent collectors are specific calculations elaborated, aimed at determining their parameters – width of the terrace bed, intermediate distances, dimensions of the collecting part and others. These serve for specifying the work volume and the quantity of materials needed.

The hydrotechical erosion control measures are calculated with the help of the popular practical formulae, accompanied by structural drawings. The volume of work to be done and the needed materials are specified.

16.9 Environment contamination control

The contribution of the measures for environment control are described, namely: erosion control, afforestation, grass growth, landscape arrangement, contamination control of the soils and the water sources, building of recreation projects, and others.

16.10 Security and hygiene of labour, fire control

The regulations on the security and hygiene of labour are described, which have to be kept with the execution of the project and with carrying-out the technological operations in plant growing, cattle breeding, timber industry, and the other activities.
The measures which have to be conducted for conservation of the buildings, forests and crops from fires are described.

16.11 Design on the organization and execution of building work

1. An explanatory note containing a description of the technologies of execution of the building and assembly operations in the predetermined terms is drafted.
   The technology applied for erecting the buildings, the construction of roads, meliorative and erosion control undertakings is described, taking into consideration

the possibilities for the highest mechanization of the processes, the use of prefabricated elements, cheaper materials and such that can be supplied from places adjacent to the building sites.

2. A lay-out plan of the building region on a 1: 25,000 scale, on which the building sites and these sites from which building materials are to be obtained (if they are in the same region) is drawn.
3. General building plan of the projects – containing the accepted sites, is to be drawn on a 1: 10,000 scale.
4. Complex generalized time-table on the consecutive execution of the building-assembly work and other activities:
   - determining the terms for conducting the building stages and finishing the subsites on a continuity corresponding to the production process and conservation of the ecosystem. With the erosion control measures it should be commenced at the upper part of the water-collecting area, and consecutively individual small water collectors are built;
   - distribution of the capital investments, building and assembly work by years.
5. General building programme.
6. List of the volume of the basic and special building work by years.
7. Total table on the basic materials needed – by sites and building stages.
8. List of the machines and equipment needed for conducting the technologies.
9. Diagram on the work-force.
10. Accounting documentation of the temporary buildings.

16.12 General account

It is composed on the basis of the accounts or the individual parts, sites, subsites and it determines the total cost for the execution of the project.
Individual general accounts are prepared for each one of the building stages.
Such are prepared individually for the building work which will be carried out by different organizations and institutions.
The general accounts contain separate parts on the types of measures, residential buildings, production buildings, roads, irrigation, drainage, erosion control, etc.

16.13 Technical-economic part

1. Basic initial data from the technical-economic assignment.
2. Basic technical economic indices – total area, total production by sectors, building cost, and others.
3. Considerations proving the progressive character of the technologies introduced in the production work.
4. Degree of specialization.
5. Data on the economic connections of the project.
6. Basic demand on machines, materials (fertilizers, chemicals and others), water, work force, etc.
7. Analysis of the capital investments.

8. Calculations and analysis of the technical-economic indices (labour productivity, depreciation term, and others).

With the elaboration of the technical-economic report, obligatorily two variants must be prepared. They are both presented with the discussions on the project. On the basis of the variant accepted and approved by the expert committee the executive plan is later elaborated, which contains all the need executive drafts and lay-outs.

Literature

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Onchev N. Predicting the areal water erosion in the People's Republic of Bulgaria, and optimizing the agrotechnical erosion control and meliorative measures. Doctor's dissertation, S. 1977.

17 Land suitability evaluation based on resistance to erosion and other land qualities in a part of Kilifi District

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Abstract

A physical land evaluation study was made of 13,000 ha of rolling to gently undulating land in Kilifi District.

The present land use, comprising cultivation of both perennial and annual crops and extensive grazing in some areas are all at a low level of technology. At this level poor soil conservation measures are taken resulting in accelerated soil erosion. Thus this study was made to assess the suitability of land for the present land utilization types with due emphasis on resistance to erosion.

A soil survey (scale 1: 50,000) carried out to form the basis of the evaluation showed that the major soils are Arenosols, Ferralsols, Nitosols, Acrisols and Luvisols on the sloping areas while Gleysols, Cambisols, Lithosols and Fluvisols are found in the minor valleys and lowlying areas.

The well drained soils on the sloping areas are marginally suitable for coconuts and moderately suitable for cashewnuts, while they are marginally suitable for maize. Poorly drained soils in the low-lying areas are not suitable for both the perennial crops and maize due to vertic properties and low availability of oxygen.

To reduce the erosion rates, improved management of both tree crops and annual crops is needed. This will for the tree crops provide protective canopy cover while for the annual crops will take into account the necessary soil conservation measures. Thus erosion will only be reduced through improved levels of technology and increased technical knowledge of the farmers.

17.1 Introduction

The study area, comprising 13,000 ha, lies in Kilifi District, Kenya. It is bound by longitudes 39°32′25E and 39°48′15E and latitudes 3°45′S and 3°47′S. The landscape is gently undulating to rolling with overall slopes ranging from 2% to over 22% and falls in agro-climatic zones III, IV and V which are classified as hot humid to semi-arid (Sombroek et al., 1982).

The present land use comprises rainfed arable cultivation of both perennial crops – coconut, cashew, citrus and annual crops – maize, simsim, cassava, pulses and cotton. In some parts grazing is the predominant land use.

The level of technology employed is low (traditional) which does not take into account adequate soil and water conservation measures. Consequently the area is currently undergoing accelerated erosion to varying degrees depending on the soil type and the present land use.

Due to increasing population pressure, there is a tendency to increase agricultural production through cultivation on steep slopes and on highly erodible soils. This trend is however not accompanied by the soil conservation measures required to contain and/or reduce soil erosion to acceptable levels.

This land evaluation study was thus carried out to assess the suitability of land for the various uses relevant to the area and subsequently make land-use recommendations which attempt to minimize land degradation while at the same time improving or sustaining the yields. Since soil erosion is one of the major limitations, this paper gives it the due emphasis. Other land qualities/characteristics used include availability of moisture, nutrients and oxygen, presence of overgrazing and possibilities for mechanization.

17.2 Methodology

A soil survey at the scale of 1: 50,000 was carried out to form the basis for land evaluation. The physiographic and element analysis method (FAO, 1967) was used to interpret the aerial photographs (scale 1: 50,000). Field checks comprising of augerhole observations were made to confirm the soil boundaries after which profile pits were made and described at representative sites following the 'Guidelines for Profile Description' (FAO, 1977). At each site the information on landform, relief, slope, present land use and erosion status as recorded. Finally the profiles were sampled per horizon for both physical and chemical analyses.

For principles and concepts outlined in the 'Framework for land evalation' (FAO, 1976) were followed in the evaluation procedure. The land utilization type (LUT) concept (Beek, 1978) was applied to specify the uses in terms of the attributes produce, capital and labour intensity, level of technology employed and the technical knowledge of farmers.

The land quality concept (Beek and Bennema, 1972) was applied in the selection of the diagnostic criteria. The selected diagnostic criteria were studied and rated and were subsequently used to specify the land suitability classes for the relevant LUTs.

The rating schemes for the land qualities were adopted from Gatahi (1983). The land quality (LQ) resistance to erosion was estimated through the characteristics slope length, slope angle, rainfall erosivity and soil erodibility. Slope length (subrating R1) and slope angle (subrating R2) were determined in the field. The rainfall erosivity (subrating R3) was calculated from mean annual rainfall (x in mm) and kinetic energy (KE) using the regression equations for coastal Kenya (Moore, 1979).

$$KE = 22.82\,x - 15795$$
$$R = 0.029\,KE - 26.0 \text{ where } R = \text{erosivity factor (ft.tons/acre/year)}$$

The soil erodibility (subrating R4) was based on laboratory determinations of % carbon (subrating R1), flocculation index viz. the ratio of natural clay to dispersed clay in per cent (subrating R2) and the silt to clay ratio (subrating R3). The sum of the subratings R1, R2 and R3 was rated as R4.

The infiltration rates through a rainfall simulation was also determined for some major mapping units.

The final rating on resistance to erosion was obtained as a product of the subratings

R1, R2, R3 and R4. The rating scheme employed for these characteristics is presented in Tables 17.1 and 17.2.

The land quality availability of moisture was determined for coconuts and cashew through the moisture deficits experienced by these crops over selected periods. The available moisture storage capacity (pF 2.0-pF 4.2) was determined for each mapping unit over the rooting depth for each crop.

The monthly evapotranspiration was calculated from Woodhead's (1968) equation as modified by Braun (1977) for the coastal area, viz. distance from the coast (in kilometres) and altitude (in metres) respectively.

Table 17.1 Subrating R1, R2 and R3.

Rating	R1-slope length (in metres)	R2-slope angle (%)	R3-erosivity factor (ft.ton/acre/year)
1	<50	<	<100
2	51-100	6-8	101-200
3	101-200	6-16	201-300
4	201-300	17-30	301-400
5	>300	>30	>400

Table 17.2 Subratings r1, r2, r3, R4 and final rating of resistance to erosion.

Rating	r1-%	r2-F1%	r3-silt/clay	R4-r1,r2,r3	Product R1*R2*R3*R4
1	>2	>70	<0.2	3-4	<8
2	1-2	50-70	0.2-0.4	5	0-40
3	<1	<50	>0.4	6	41-170
4	–	–	–	7	171-320
5	–	–	–	8-9	>320

Availability of nutrients was assessed through cation exchange capacity (CEC, subrating R1, base saturation R2, available cations and %C and phosphorus R3). The final rating of this land quality was obtained by summing up the subratings R1,R2 and R3. The scheme employed is as in Table 17.4.

$Ec = 2175 + 2.47Y - 0.358h$ where Y and h are

The monthly deficit (monthly rainfall – monthly evapotranspiration) was calculated taking into account the available moisture storage capacity and infiltration rates. These deficits were regressed against yields; for coconuts the deficits occurring over 24 months before the harvest period, and the August-December deficits for cashew were used to rate this land quality. The rating classes 1,2,3,4 and 5 were selected to represent 15%, 30%, 45% and 60% decline in the yields from the maximum when the moisture deficit is zero. The rating scheme used is given in Table 17.3.

The subrating R3 (available cations, %C and phophorus) was obtained as the sum of each subrating. The R3 classes were grouped as class 1; <7, class 2; 8-12, class 3; 13-17, class 4; 18-22 and class 5; >23. The final rating of availability of nutrients

Table 17.3 Rating for available moisture for coconuts and cashew.

Rating class	24 month moisture deficits for coconuts	August-December deficits for cashew
1	0-570	< 160
2	571-1140	161-320
3	1141-1700	321-470
4	1701-2200	471-625
5	> 2200	> 625

Table 17.4 Ratings for availability of nutrients.

CLASS	RI-CEC me/100g soil	R2-base saturation %	Ca^{++}me/ 100g.s	Mg^{++}	K^{+}	%C	P(ppm) Mehlich	Final rat. R1ρ2ρ3
1	> 16	> 75	> 15	> 3.0	> 1.2	> 5	> 80	> 4
2	10-16	50-75	10-15	1-3	0.6-1.2	2.0-5.0	40-80	5-7
3	5-10	35-50	5-10	0.5-1	0.2-0.6	1.0-2.0	20-40	8-9
4	2-5	35	2-5	0.2-0.5	0.1-0.2	0.5-1.0	10-20	10-12
5	< 2	–	< 2	< 0.2	< 0.1	< 0.5	< 10	< 13

was then obtained as the sum R1 + R2 + R3.

The availability of oxygen was assessed qualitatively from the internal drainage classes adopted from the Soil Survey Manual. Possibilities of mechanization was obtained from subratings slope %, (R1), depth to bedrock (R2) and distance between the rocks; the lowest of these subratings determining the final rating.

The presence of overgrazing was assessed qualitatively by visual observation of bareground after grazing.

The study area lies in agroclimatic zones III, IV and V with a bimodal rainfall pattern whose peaks decrease from 240 mm in the east to 140 mm in the west during the 'long rains'. It can be subdivided into four physiographic units, viz. plateau, dissected uplands, dissected plains and minor valleys. Due to differences in parent materials the soils show varying physical and chemical characteristics.

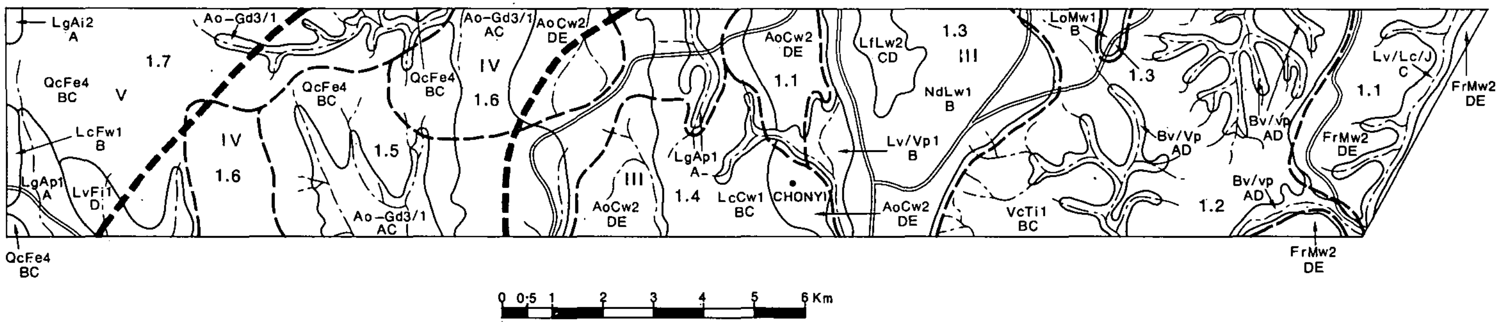
Six major soil types viz. Vertisols, Arenosols, Nitosols, Ferralsols, Acrisols and Luvisols and four minor ones viz. Gleysols, Cambisols, Fluvisols and Lithosols were identified and delineated into sixteen mapping units as shown on soil map No. 1.

On the plateau are the Ferralsols (unit FrMw2) which are well drained, very deep, sandy clay loams with low organic matter content and CEC. On the strongly dissected uplands are Vertisols (unit VcTil) which are imperfectly drained, deep cracking clays which are strongly eroded on the steeper slopes.

On the slightly dissected uplands are Nitosols (NdLwl), Acrisols (units AoCw2, Ao-Gd 3/2) and Luvisols (units LcCw2, LfLw2 and Lv/Vp/I) which are well drained, deep to very deep, sandy clay loams to sandy clay except units Ao-Gd 3/1 and Lv/Vp/I in topographically lower areas which may be shallow and imperfectly drained to poorly drained. These soils have a moderate to high cation exchange capacity.

On the slightly dissected plains are Arenosols (unit QcFe4) which are excessively

SOILS AND PRESENT LAND UTILIZATION TYPES MAP OF CHONYI – KALOLENI AREA (MAP 1)



LEGEND

(SOILS)

VcTi1	imperfectly drained, deep to very deep; yellowish brown to light olive brown, very firm, cracking clay, overlying shale fragments **(chromic VERTISOLS)**
QcFe4	excessively drained, very deep, yellowish brown to pale brown, loose, very fine sand to loamy very fine sand **(cambic and albic ARENOSOLS)**
FrMw2	well drained, very deep, dark red to dusky red, friable sandy clay loam, underlying 10–30cm sandy loam **(rhodic FERRASOLS)**
AoCw2	well drained, very deep, red, friable sandy clay loam, overlying 20–40cm coarse sandy loam **(orthic ACRISOLS)**
LgAp1	poorly drained, moderately deep, brown to yellow, mottled, very firm clay, underlying 10–20cm very dark greyish brown, friable clay loam **(gleyic LUVISOLS)**
LgAi2	imperfectly drained, very deep, yellowish brown to light olive brown, mottled, very firm clay loam, with calcium carbonate concretions **(gleyic LUVISOLS)**
LvFi1	imperfectly drained, deep to very deep, yellowish brown to light olive brown, mottled, very firm, cracking sandy clay, underlying 10–20 cm fine sand to loamy fine sand **(vertic LUVISOLS)**
LfLw2	well drained, moderately deep to deep, dark reddish brown, friable sandy clay loam, overlying concretionary nodules; in places over ironstone **(ferric LUVISOLS)**
LcFw1	well drained, deep, dark reddish brown, firm to very firm, sandy clay, underlying 0–10cm sandy loam **(chromic LUVISOLS)**
LcCw1	well drained, very deep, yellowish red to strong brown, friable to firm, sandy clay; in places sand **(chromic LUVISOLS)**
LcMw1	well drained, very deep, yellowish red, friable to firm, sandy clay, with 10–25cm sandy clay loam topsoil; in places overlying concretionary nodules **(chromic LUVISOLS)**
NdLw1	well drained, very deep, dark red to dusky red, friable, fairly rocky, sandy clay to clay **(dystric NITOSOLS)**
Ao-Gd 3/1	association of: – well drained, very deep, yellowish red to yellowish brown, friable to firm, fine sandy loam, overlying 20–60cm fine sand **(orthic ACRISOLS)** – poorly drained, very deep, grey, mottled, firm to very firm, sandy clay to clay **(dystric GLEYSOLS)**
Lv/Vp/l	complex of: – – imperfectly drained, very deep, yellowish brown, firm clay loam **(vertic LUVISOLS)** – poorly drained, deep, dark yellowish brown to dark greyish brown, very firm, cracking clay **(pellic VERTISOLS)** – well drained, shallow, brownish yellow to dark brown, sandy clay loam, overlying bedded limestone **(LITHOSOLS)**
Bv/Vp	complex of: – –imperfectly drained, very deep, light olive brown to light brownish grey, mottled, firm, cracking clay **(vertic CAMBISOLS)** – poorly drained, very deep, very dark greyish brown, very firm, cracking clays **(pellic VERTISOLS)**
Lv/Lc/J	complex of soils of varying drainage conditions, depth, colour, consistence and texture **(vertic LUVISOLS, chromic LUVISOLS and FLUVISOLS)**

(L.U.T'S)

1.1	cultivation of perennial crops, cashew nut dominant; low level of technology
1.2	cultivation of annual crops, maize dominant; intermediate level of technology
1.3	cultivation of perennial crops, coconut dominant; low level of technology
1.4	cultivation of perennial crops, coconut and citrus dominant; low level of technology
1.5	mixed farming, coconut dominant, unimproved cattle; low level of technology
1.6	cultivation of perennial crops, coconut and cashew nut dominant; low level of technology
1.7	extensive grazing of zebu cattle; low level of technology

KEY

NdLw1 .... soil mapping symbol
B .... slope class symbol
soil boundary
land utilization type boundary
road
agro–climatic zone boundary
river
1 Sq. cm 625 ha

Drawing No. 84094

drained, very deep, friable sandy loams to loamy sands. Luvisols (units LcFwl and LvFil) which also occur in this physiographic unit, are well drained to imperfectly drained, moderately deep to deep clays with moderate CEC values.

The minor valleys comprise Luvisols (units LgApl, LgAi2) and complexes of Luvisols, Cambisols, Vertisols and Fluvisols (units Bv/VP, Lv/Lc/J) which are poorly drained, deep to very deep clays with vertic properties except the Fluvisols which are stratified and sandy. A brief description of each unit is given in the soil map legend. Some infiltration data and soil moisture storage capacity are given in Table 17.5.

Presently the land is used for arable rainfall cultivation of perennial crops together with annual crops either intercropped or in separate stands. The level of technology applied is low but the land preparation for annual crops is partly mechanized and is therefore considered an intermediate level of technology. Based on the percentage covered by specific crops, seven land utilization types (LUTs) were described and delineated on the soilmap. These include:

1.1 Cultivation of perennial crops; cashew dominant, low level of technology;
1.2 Cultivation of annual crops; maize dominant, intermediate technology;
1.3 Cultivation of perennial crops; coconut dominant, low level technology;
1.4 Cultivation of perennial crops; coconut and citrus dominant, low level of technology;
1.5 Mixed farming, coconut dominant, low level of technology;
1.6 Cultivation of perennial crops, cashew and coconut dominant, low level technology;
1.7 Extensive grazing low level of technology.

The quantifiable attributes for each LUT are given in Table 17.6.

Table 17.5 Moisture storage capacity and infiltration rates.

Mapping unit	Moisture storage capacity		infiltration rates mm/hr
	for tree crops	for annuals	
VcTii	–	91 mm	110
FrMw2	218 mm	107 mm	125
LcLw1	269	138	120
NdLw1	297	127	130
Lv/Vp/J	209	168	
AoCw2	142	74	135
LcCw1	270	126	120
Ao-Gd 3/1	295	131	130*
Ao-Gd 3/1	138	61	60**
QcFe4	61	47	135
LcFw1	120	120	120
LvFi1	95	95	120
LgAi2	129	72	55

* infiltration rates for orthic Acrisol component
** infiltration rates for dystric Gleysol component

Table 17.6 Quantifiable key attributes for the present land utilization types.

Number of LUT	Land utilization type	Produce (% area of LUT devoted to crops)	Production costs KSh.per hectare	Labour intensity mandays per hectare	Farm power	Level of technology
1.1	Cultivation of perennial crops, cashew dominant; low level of technology	Tree crops 50-70% Annual crops 10-20% Bush 20-40%	Low;(approx. KSh. 450 annually)	Low-approx. 40-50 mandays annually	Manual	Low
1.2	Cultivation of annual crops; maize dominant; intermediate technology	Maize 70-80% Cotton 10% Bush 10-20%	High;(approx. KSh. 1,000 annually)	Moderate,approx. 50 mandays annually	Partly mechanized	Intermediate
1.3	Cultivation of perennial crops, coconut dominant; low level of technology	Coconuts 40-50% Cashew 15-20% Others 10% Annuals 20-35%	Low (approx. KSh. 500 annually)	Low-approx. 45 mandays annually	Manual	Low
1.4	Cultivation of perennial crops, coconut and citrus dominant; low level of technology	Coconut 30-40% Citrus 10-20% Cashew 10-15% Annuals 40-50%	Low (approx. KSh. 500)	Low (about 50 mandays annually)	Manual	Low
1.5	Mixed farming,coconut dominant, unimproved cattle; low level of technology	Coconut 40-80% Cashew 10-20% Annuals + pasture 30-40%	Low (approx. KSh. 380 annually)	Low (approx. 37 mandays annually)	Manual	Low
1.6	Cultivation of perennial crops; coconut and cashew dominant; low level of technology	Coconut 40-50% Cashew 30-40% Maize-intercropped	Low(approx. KSh. 300 annually)	Low (only about 25 mandays annually)	Manual	Low
1.7	Extensive grazing, zebu cattle; low level of technology	Pasture 70-90% Crops 10-30%	Low (approx. KSh. 200 annually)	Low (only about 20 mandays annually)	Manual	Low

17.3 Ratings of land qualities

The ratings of each land quality for each mapping unit is given in Table 17.7 which indicates that units VcTi1, FrMw2, AoCw2, LcC1 and Ao-Gd 3/1 are very susceptible to erosion (rating 4).

Physically, steep slopes, low organic matter contents are the major causes for the high susceptibility to erosion in units FrMw2, AoCw2, LfLw2, LcCw1 and Ao-Gd 3/1, while the clay mineralogy viz. the 2:1 lattice clays which swell and disperse when wetted and the high silt to clay ratios are the main factors in unit VcTi1. The accelerated soil erosion is caused by the management practices employed; for example ploughing down slope, burning of residues and lack of cut-off drains in areas where annual crops are cultivated.

The extent of overgrazing is variable, units QcFe4, LvFi2 and Ao-Gd 3/1 are severely overgrazed. This overgazing results from the tenure system of communal grazing. There is neither control of stocking rates nor collective responsibility towards soil conservation measures.

Soils on the slopes are well aerated except VcTi1 and LvFi1 which show vertic properties and are rated 3 while the units in valleys viz. LgApl, LgAi2, Lv/Vp/I, Bv/Vp and Lv/Lc/J are poorly supplied with oxygen and are subject to occasional flooding and are thus rated in classes 3 and 4.

The availability of moisture is low for coconuts but is slightly higher for cashew which has lower moisture demands. Most of the units are of a low to moderate fertility status except those units with sandy clay to clay textures.

17.4 Suitability classification

The suitability classification was obtained by matching the LUTs ecological requirements with the present land qualities through conversion tables. Conversion tables are difficult to find in literature. Further it is difficult to make the conversion tables for LUTs comprising of crops with different ecological requirements. To overcome this difficulty, conversion tables were made for each crop by considering the requirements of the crops as given in literature. There is a general lack of specific data on the requirements of tree crops consequently the conversion tables for these crops are rather general. The conversion tables for coconuts and cashew are given in Table 17.8 while that for maize is in Table 17.9.

The suitability classification for each mapping unit for each crop is given in Table 17.10.

Table 17.10 indicates that the well drained soils on sloping areas are marginally suitable (class S3) for coconuts, moderately suitable (class S2) for cashewnuts and marginally suitable (class S3) for maize.

The major limitations for coconuts is the availability of moisture and nutrients in these units. For cashewnuts the major limitation is the rainfall during the flowering and harvesting period (not discussed here) while high susceptibility to erosion and low availability of nutrients and moisture are the major limitations for maize.

The units occurring in low lying areas and units VcTi1 and LvFi1 are not suitable for tree crops and are only marginally suitable for maize. The major limitation for

Table 17.7 Rated land quality for each mapping unit.

Land quality \ Mapping unit	VcTil	QcFe4	FrMw2	AoCw2	LgAp1	LgAi2	LvFil	LfLw2	LcFw1	LcCw1	LcMw1	NdLw1	Ao-Gd3/1	Lv/Vp/I	BvVp	Lv/Lc/J
*Resistance to soil erosion	4	3	4	4	1	2	3	4	3	4	3	3	4	3	3	3
Availability of (a)	4	5	4	4	4	4	4	4	4	4	4	3	4	4	4	3
moisture (b)	3	3	2	2	2	2	3	3	3	3	2	2	3	2	3	2
Availability of nutrients	2	4	3	3	2-3	2	2-3	3	2	3	2	2	4	2	2	2
Availability of oxygen	3	1	1	1	4	3	3	1	1	1	1	1	2+4	3	4	3+4
Possibility of mechanization	2	1	5	3	1	1	2	4	2	2	1	4	2	5	3	5
Presence of overgrazing	3	2-3	–	2	1	2	3	–	2	1-2	1	–	2-3	–	–	–

*extensive grazing is not present

Table 17.8 Conversion tables for coconuts (a) and cashewnuts (b)

Land quality / Suitability class	Susceptibility to soil erosion	Availability of moisture	Availability of oxygen	Availability of nutrients
Highly suitable	(a) 1,2	1	1,2	1,2
S1	(b) 1,2	1	1,2	1,2
Moderately suitable	(a) 3,4	2	1,2	3
S2	(b) 3,4	2,3	1,2	3
Marginally suitable	(a) 5	3,4	3	4,5
S3	(b) 5	4	3	4,5
Not suitable	(a) –	5	4	–
NS	(b) –	5	4	–

Table 17.9 Conversion table for maize

Land quality / Suitability	Agroclimatic zone and available moisture storage capacity	Susceptibility to soil erosion	Availability of oxygen	Availability of nutrients
Highly suitable S1	III; > 150 mm	1,2	1,2	1,2
Moderately suitable S2	III; 80-150 mm IV; > 150 mm	3	3	3
Marginally suitable S3	III; 40-80 mm IV; 80-150 mm V; > 100 mm	4	4	4
Not suitable NS	III; < 40 mm IV; < 80 mm V; 100 mm	6	5	5

the tree crops are availability of oxygen together with cracking clays which destroys the roots of the tree crops. For maize the occasional flooding is the major limitation.

17.5 Conclusion and recommendations

Susceptibility to soil erosion was observed as a major limitation on the sloping areas and this situation has to be arrested. Although the study of the suitable conservation measures is outside the scope of this study some measures may be suggested. The cultivation of tree crops has advantages since their canopies provide protective cover which effectively reduces the rainfall erosivity. However the tree crops have to be well managed to provide this protective canopy cover. In addition cover crops for example legumes should be provided. In places where annual crops are grown adequate conservation measures must be taken. These should include cutting of cut-off drains, contour ploughing, strip cropping and suitable crop rotations.

Where the major cause of accelerated erosion, controlled grazing should be practised. The appropriate stocking rates should be established for each mapping unit to

Table 17.10 Land suitability rating for coconuts, cashew and maize.

LUT \ Mapping unit	VcTi1	FrMw2	AoCw2	LgAp1	LfLw2	LcCw1	LcMw1	NdLw1	Lv/Vp/1	Bv/Vp	Lc/Lv/J	Ao-Gd3/1	QcFe4	LvFi2	LgAi2	LcFw1
Coconut	NS	S3	S3	NS	NS	S3	S3	S3	NS	NS	S3	S3	NS	NS	NS	S3
Cashew	NS	S2	S2	NS	NS	S2	S2	S2	NS	NS	S3	S3	S3	NS	NS	S3
Maize	S3	S3	S3	NS	S3	S3	S3	S2	S2 NS	NS	S3	S3	NS	NS	NS	S3

reduce the extent of overgrazing.

All these remedial measures suggested require the improvement of the levels of technology applied and education of the farmers on both improved agronomic practices and the necessary soil conservation measures.

Acknowledgement

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Discussion

Mitchell Were the criteria used during the land evaluation tested in the field survey?
Gachene yes, testing is not only carried out in this area but also in other survey areas mapped by the Kenya Soil Survey (KSS).

McCormack: Is 'overgrazing' considered a land quality or is it a sign of how the land is being managed?
Da Costa: in the present procedure the status of the land caused by overgrazing is seen as a land quality.

Young: In the initial framework the definition of land quality included the phrase 'also past actions of man', it was however pointed out by some Dutchmen that if this was to be included in the definition of the land quality, the major part of The Netherlands would be concerned; the phrase was subsequently dropped.

18 Drip irrigation as a method for soil and water conservation in sloping areas: a case study from Malaga Province, Spain.

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Abstract

A semi-detailed soil survey was carried out in the lower Guadalhorce catchment near Malaga in Southern Spain, from May/June 1984. The main LUT of the area is 'medium to large scale, high technology, gravity irrigated farming of citrus'. This LUT occupies all the level Alluvial soils and is at present extending over sloping heavy clay soils of the valley sides, where it forms an alternative for the LUT 'large to medium scale mechanized rainfed cultivation of cereals'.

The main problem of the rainfed agriculture is the low precipitation. The main problems of the irrigated agriculture are formed by the periodic shortage and quality decline of irrigation water caused by the competing demands of tourism and industry on the scarce water resources of the area.

The citrus LUT requires the construction of very large bench terraces on the slopes which enable mechanized gravity-irrigated cultivation of this crop. As a result of the construction of these terraces, natural soil profiles are destroyed and subsoil with unfavourable properties is exposed. This results in drainage and stability problems in the winter while salinization occurs in the summer, seriously affecting growth and yield of the citrus. An alternative irrigation method is drip irrigation which does not require bench terracing.

Advantages and disadvantages of both irrigation systems for the sloping heavy clay soils are compared and preliminary conclusions and recommendations are given. They indicate that the introduction of drip irrigation may save water and conserve the slopes better, while yields are increased at a lower installation cost.

18.1 Introduction

In the Guadalhorce catchment area the government has initiated the development of irrigated agriculture. The land preparation methods carried out prior to the establishment of gravity irrigation lay-out (furrow and basin irrigation) and the efficiency of this irrigation method in comparison to drip irrigation is the subject of this paper. Data collection took place during fieldwork in May-June 1984, within the framework of training of ITC students in soil survey. A semi-detailed soil map and report are in preparation.

The extent of the levelling and terracing and the effect of it on the landscape as a whole and on the soil in particular, poses a number of questions concerning the validity of the practices in relation to other methods of irrigation.

Subsequently an area was selected for further investigations in the Guadalhorce catchment where the traditional irrigation methods are compared to drip irrigation for the same produce, i.e. citrus production.

18.2 Environmental setting

18.2.1 Location

The Guadalhorce catchment area is located in the Malaga Province, Southern Spain. The centre coordinates are 36°45′N, 4°42′E respectively (Figure 18.1). The area has good access by all weather roads and has a well developed infra-structure. The total survey area comprises 80,000 ha, of these 11,000 ha are under gravity irrigation, while a further 2,000 ha are planned, in the context of the Guadalhorce scheme.

18.2.2 Climate

According to Köppen the area has a Mediterranean type of climate (Csa) characterized by cool moist winters and warm dry summers. The winter rains are concentrated in the months October to April and comprise on average 470 mm. The area has been subject to a severe dry spell over the last 10 years, which was terminated during the

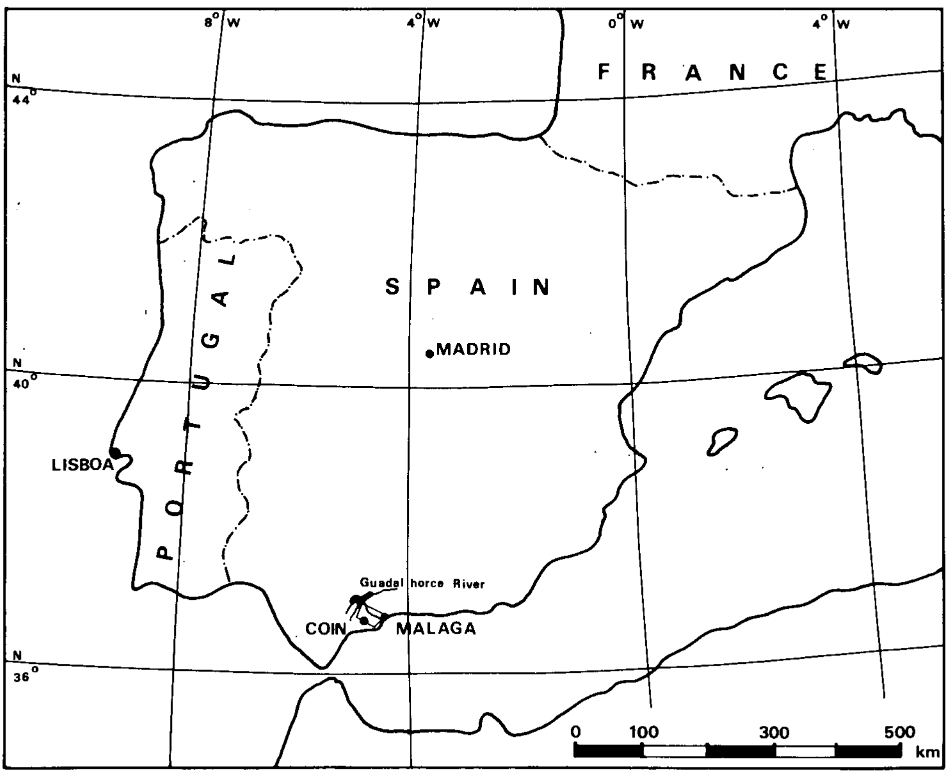


Figure 18.1 Location map of the study area. The Guadalhorce river and the complex of barrages which supply irrigation water are indicated.

1983/1984 rains. The rainfall pattern changes considerably from the coastal areas to the hinterland where higher relief causes orographic precipitation. Higher altitudes upstream cause also a drop in temperature and night frost occurrence has been reported in the survey area. There is virtually no night frost hazard in the coastal zone, where subtropical crops are being introduced.
Evaporation follows the seasonal pattern and exceeds the rainfall in the months April to October the average yearly deficit is 278 mm. Climatic differences are locally observed due to altitude and exposure.

The soil climate for well drained soil, as expressed by the USDA Soil Taxonomy (1975) in terms of the soil moisture regime and the soil temperature regime is classified as 'Xeric' for the former and 'Thermic' for the latter.

The water balance of the area in view of agricultural production shows barely sufficient rainfall in a normal year for the production of the cereals wheat/barley and sufficient moisture for olives and almonds. Crops that demand a more constant water supply throughout the year can only be grown if supplementary water is supplied.

18.2.3 Geology

The area is covered by a geological map scale 1: 50,000, Alora sheet (IGME, 1972) and accompanying explanatory text. The whole area is underlain by rocks of the Pre-Cambrian Basement System, which are exposed in several hills and mountains ranges, and have been subject to severe folding and trusting. The occurrence of rocks from the Mesozoicum is limited in contrast to those of the Tertiary period. The Flysch deposit developed as a marine sediment laid down in a geosynclinal during the Eocene-Oligocene period. This clayey unconsolidated material, which may include sandstone benches, forms the dominant parent material for the soils in question.

In some parts of the survey area it is overlain by a deltaïc marine infill, which mainly consists of fossil-bearing clays and marls. The whole region was subject to a rise of about 450 m during the last part of the Pliocene and the beginning of the Pleistocene, resulting in renewed erosion and continental deposition. The Guadalhorce river incised in the original fairly level topography and formed an alluvial plain and associated terraces.

Presently most of the man-made terracing takes place in areas underlain by the Flysch and by the 'Clay and Marl' deposit. The latter Neogene deposits seem to have a slightly lower percentage of clay but a higher percentage of silt in comparison to the Paleogene Flysch. In addition the Flysch appears to be more 'marine', i.e. higher exchangeable sodium percentage and higher salt content than the associated clays and marl. The present investigations concern mainly irrigation of soils developed on the Flysch.

18.2.4 Geomorphology

The area's topography is presented at scale 1: 50,000 (Instituto Geografico Y Catastral, 1975).

The present relief is caused by the combined effects of geological processes and geomorphological development giving rise to the formation of a number of land types. They concern mountains and hills, piedmonts, plateaus, dissected plains and alluvial valleys. The Guadalhorce river has been and still is actively involved in the further shaping of the relief. The Flysch landscape and to a certain extent also the 'Clay and Marl' landscape may be described as a steeply dissected to undulating plain, developed on unconsolidated marine sediments at an altitude of 200-250 m. The interfluves have a gentle relief (2-8%) slope, but the valley sides have slope gradients of 30% or more. Valleys are usually V-shaped, with convex tops and concave transitions to the valley bottom. Where the Flysch landscape is associated with the hills and mountains, relief and slopes are more pronounced, in addition to the occurrence of sandstone outcrops, which presumably represent another facies during the deposition of the generally clayey Flysch sediments.

The occurrence of landslides is common on the steeper terrain and is attributed to the composition of the parent material (see previous par.). There is little visible evidence of erosion under the present conditions of land use apart from these slumps and some gullies.

18.2.5 Soils

Soil information was gathered during six weeks in May/June 1984.
Observations were carried out by auger and soil pits in addition to road cuts and quarries. The major soil in the Flysch landscape is classified as a Entic Chromoxerert clayey, montmorillonitic kaolinitic, calcareous, thermic. (Soil Survey Staff, 1975). According to the FAO-Unesco (1974) the soils classify as Chromic Vertisols. These Vertisols are considered deep, moderately well drained to well drained, dull yellowish brown, calcareous, cracking fine to very fine clays. Vertic properties are well developed, apart from gilgai micro-relief which is generally obscured by soil management practices, as virtually the total area of these soils is in agricultural use at present.

The occurrence of these Vertisols is not limited to the flatter areas and/or depressions but they are also found extensively on steep to very steep sloping terrain, with slopes of 30% or more. Even in these positions the soils are well developed apart from a small colour difference and show little or no signs of truncation or degradation.

The solum is clayey throughout, the percentage clay 60% or more, while the percentage fine silt is around 10% and the percentage coarse silt around 5%. The percentage fine and very fine sand varies between the 10-20%. With depth there is a significant decrease in the percentage sand but an increase in the amount of silt and clay.

The pH is high throughout which is in accordance with the relatively high amount of CaCO3 and CaSO4, but does not correspond to high ESP values in the BC and C horizons, presumably because of the presence of Mg and Ca on the exchange complex. Base saturation is 100%, while CEC(soil) is well above 24 meq/100 g.

The natural salinity is low in the upper part of the solum but increases with depth and classifies as slightly saline in the C horizon (data from non-irrigated soil).

Organic matter is low in the top soil and decreases regularly with depth, corresponding C/N values are around 6 and decrease till 1.5 in the C. Clay mineralogical analysis indicate the equal presence of kaolinite and smectite in the upper three horizons, whereafter the percentage kaolonite increases. This may explain the general decrease in

Figure 18.2 Panorama of a bench terraced valley slope under gravity irrigation. Note that every individual landowner used different methods and specifications for the construction of the terraces. Step heights vary from 1 to several meters. Some terraces were made by mule drawn ploughs. The main tendency is for large step heights which require heavy machinery.

the CEC(clay) values with depth.

A complete soil profile description of a representative Vertisol of the Flysch landscape is given in the Appendix 18.1.

18.2.6 Hydrology

The area is drained by the Guadalhorce river which rises in the Archidona area and discharges near Malaga in the Mediterranean Sea.

The natural habit of the river has been changed by the construction of three barrages (dams) at Gualdalteba, Conde del Guadalhorce and Guadalhorce at the junction of the Guadalhorce river and two tributaries. In addition canals have been constructed to conduct storage water to the coastal zone, in particular Malaga, for human and industrial consumption, while in the survey area concrete irrigation canals and pipes have been installed for the supply of irrigation water.

Several older towns in the area obtain part of their water supply from springs and wells originating from the travertine formations on which these settlements have been constructed.

The discharge of the Guadalhorce tributaries varies considerable from year to year and from season to season. In the summer months the main flow may be reduced to a trickle while heavy rainfall in the winter months may cause flooding. The scarcity of water in the dry season puts emphasis on an efficient water use specially with regard to the tourists and other industries at the one hand and agricultural use on the other hand. The high value of first quality agricultural, produce, i.e. lemons and oranges for the export market in particular within the common market requires a reliable water supply throughout the year. In this respect the optimalization of the irrigation methods warrants high priority. While quantity of water is limited in some years, the quality of water is also subject to change. This is caused by the occurrence of a saline spring on the bottom of one of the dams, causing the release of NaCl in the water. While during normal years the input of this water is limited, in dry years it is necessary to obtain sufficient water to meet demands. The application of saline water for irrigated agriculture constitutes a hazard, which could be reduced by adapted irrigation practices.

18.3 Land use

In the area three major land uses are distinguished, i.e. rainfed agriculture, irrigated agriculture and extensive grazing. In terms of the FAO Framework for Land Evaluation (FAO, 1975) ten land utilization types (LUT's) were described.

18.3.1 Rainfed agriculture

Those pertaining to rainfed agriculture include:
1. the cultivation of cereals with or without rotation of pulses, occasionally with some sheep and/or goats,
2. the cultivation of olives and/or almonds often in association with other sources of income.

In normal rainfall years yields are relatively low, up to 2/ton/ha for wheat and/or barely while yields of olives range from 15 to 30 kg tree/year.

The LUT's are further characterized by farm size, on the larger farms (> 50 ha) management is largely mechanized, while on the smaller farms, which often occupy strongly sloping and/or stony land, farming operations by hand are common. They include stone clearing practices in those parts of the Flysch landscape where sandstone is exposed or is close to the surface and where sandstone fragments are brought up by the churning processes common to the Vertisols. However, stone clearing is also carried out on mechanized farms to obtain large enough fields for farming operations. Prior to the introduction of irrigation in about 1960, most of the area was under rainfed cultivation of annuals and perennials, except for some parts of the alluvial plain where irrigation practices have been in vogue for a long time, and near villages where local springs or wells supplied irrigation water for small farm operations, like vegetables and fruits. The recent drought in the area, which seems to have ended by the winter rains 1983/1984 caused a sharp decline in agricultural produce, making the introduction of irrigation an attractive proposition.

No soil conservation measures were observed, occasionally adverse management practices are carried out (ploughing perpendicular to the slope).

18.3.2 Irrigated agriculture

The irrigated agriculture in the area is mainly focussed on the production of perennial fruits. Of these, citrus, especially lemon, is the main crop while apricots, peaches and pears occupy minor areas. Interesting tropical fruits which have been introduced rather recently are nisperas and avocado pears.

The irrigated land use has further been defined by key attributes into four land utilization types; they concern:

- small to medium scale, medium to high technology, gravity irrigated farming of vegetables, citrus and some fruit,
- small to medium scale, medium to high technology, gravity irrigated farming of mixed fruit and vegetables,
- medium to large scale, high technology, gravity irrigated farming of citrus, mainly lemon and orange, occasionally with vegetables,
- large scale high technology, drip-irrigated farming of citrus with vegetables and some fruit trees.

The latter two LUT's form the main topic of this publication.

The main irrigated areas are the Guadalhorce valley bottom and the alluvial plains of its tributaries and the adjacent valley slopes which have been converted into bench terraces to a large extent for this purpose. (Figure 18.2) The main irrigation system draws its water from the 3 dams of the Guadalhorce river and commands at present 11,000 ha, which will extend in due course to 13,000 ha. Various local systems exist which draw their water from local sources and often date back to the Morish period. The local schemes which were drawing their water from the Guadalhorce river proper are now being incorporated into the main Guadalhorce scheme.

The main government agency for the development of the agriculture in the area is IRYDA (Institute for Land Reallocation and Agricultural Development) which stimulates the development with subsidies and loans on favourable terms.

Part of the development costs are incorporated in the annual irrigation charges which vary at present from 4,300 Pts/ha for old irrigation schemes incorporated in the Guadalhorce scheme to 6,700 Ptas/ha for agricultural areas into which irrigation was introduced and to 9,100 Ptas/ha for new irrigation areas of which the entire infrastructure has to be established. These charges are gradually introduced for newly started farmers; subsequently it takes 10 years before the full yearly amount is levied.

The dominant irrigation practice is the traditional check irrigation (basins containing one or more trees) or flood irrigation. Drip (trickle) irrigation is being introduced by a number of farmers for citrus and avocado. This development is mainly taking place outside the Guadalhorce scheme using local water supplies. The Guadalhorce scheme does not favour this new development since its water-pricing system does not offer any incentive for water-saving measures and since its water-distribution timetable does not fit the requirements of drip. This situation is very similar to the one described by Lyons (1977) for the citrus culture in Texas U.S.A. Moreover transport of water saved by farmers to fields outside the established perimeter of the scheme is not tolerated.

The irrigation season has a duration of 4 months and lasts from May till September. Water is applied to citrus with a frequency of 30 days on medium textured and heavier soils and with a frequency of 20 days on lighter textured soils. Other fruits harvested early in the irrigation season are irrigated with a lower frequency after the harvest. An average irrigation intensity of about 4mm/day can be computed for the whole scheme, from data about the amount of water suppied for 11,000 ha in 1982 in the period May/September. This tallies with the maximum capacity of the main canal of 7 m^3/sec if the amount destined for comsumptive use of the city of Malaga is deducted.

The amounts of water reported to have been received by individual citrus farmers for gravity irrigation vary from 4.9 to 4.0 mm if recalculated to a daily basis. An apricot farmer reported receiving an equivalent of 2.3 mm/day during the irrigation season. Many farmers complained about poor quality water.

Drip-irrigated citrus was reported to receive an equivalent of 0.2 mm/day for recently planted trees, 0.7 mm/day for half grown trees and 1.5-2 mm/day for fully grown trees. Similar amounts seem to apply for avocado trees. More details about water use will be given in the following sections.

The main harvest of lemons falls in the spring period. A minor but very valuable harvest of so-called summer lemons is reported for certain varieties in August.

The best yields are reported for lemon groves on the Guadalhorce alluvium: 32 tons per ha per year, 20-25 tons per ha seems to be a reasonable average.

For bench-terraced lemon groves on heavy soils, yields of less than half those on the alluvium seem to be common (about 10 tons/ha). A drip- irrigated lemon grove on sloping heavy soils of the F landscape of 7 years old and not yet in full production was reported to produce about 17 tons of lemons/ha (see Figure 18.3).

Prices of lemons are commonly around 20 Ptas/kg in the main harvest period. Prices of up to 125 Ptas/kg are said to have been paid in special cases. In times of bumper crops prices may fall as low as 6 Ptas per kg. The cost of picking being in the order of 3 to 4 pesetas/kg.

18.4 Current soil and water conservation problems

18.4.1 Rainfed agriculture

At present most of the soils of the Flysch (F) landscape are in use for rainfed agriculture. The main problem for the rainfed annuals is the low precipitation. The water balance for wheat (Figure 18.4) shows that for an average year and assuming a storage capacity in the root zone of 100 mm and 100% effective rainfall, severe moisture deficits occur in the yield formation and ripening stages. These moisture deficits are the main cause for the average low yields reported. Comparison of the two graphs representing early and late sowing shows the importance of choosing an early planting date whenever possible. The Vertic properties of the soils form an impediment for mechanization and make moisture conservation measures such as dust mulching difficult.

The fact that the first rains disappear into the open cracks of these soils, effectively preventing the moistening of the topsoil to a state that allows plowing, is probably the cause for the relatively late sowing practised in the area.

On the steeper slopes the effectiveness of the rainfall will be much lower than 100%. As such the moisture deficit on such soils will be much more severe. This factor and the additional impediment to mechanization caused by the steeper slopes causes such

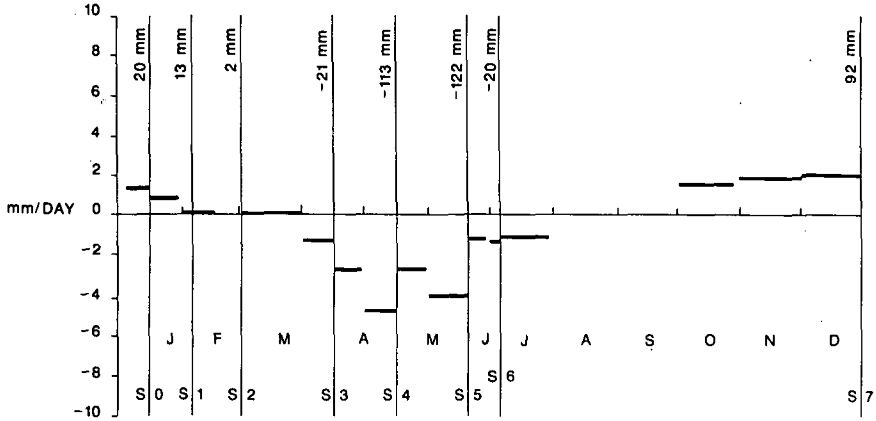
Figure 18.3 Drip irrigated lemon groove on a slope of about 20 percent in the F landscape. The plantation is 7 years old and is already producing yields comparable to the average on the alluvial soils (17 tons/ha). The soils are Entic Chromoxerets. Only stone removal was performed prior to planting. At present small terraces are formed spontaneously due to the movement of caterpillar tractors between the tree rows that have been planted along the contour lines.

areas to be in use mainly for rainfed perennials such as olives and almonds.

Evidence of soil erosion in the form of gullies has been found so far mainly on the steepest slopes in clean cultivated olive and almond groves. It seems that mass movement as a degradational process exceeds erosion in importance, at least under natural circumstances, in this landscape. This is remarkable since one would expect more evidence of erosion on these sloping impermeable heavy clay soils, when subjected to a type of agriculture that does not take any conservation measures. The soils have a stonecover under natural circumstances. This cover is due to the excretion of the sandstone fragments of the Flysch by the Vertisols. Relatively recently these soils have been brought under agriculture and stone removal has been practised on a large scale. The protection afforded by the stonecover may have been the cause for the absence of strong erosion features. The relatively recent removal of this stonecover may not have allowed sufficient time to pass for erosion-features to become evident. This may however change in the near future.

18.4.2 Irrigated agriculture

Currently the main problems of the irrigated agriculture are the following. For the entire area shortages of water have been frequent in the last few years due to drought which has forced the rationing of irrigation water. The quality of the irrigation water

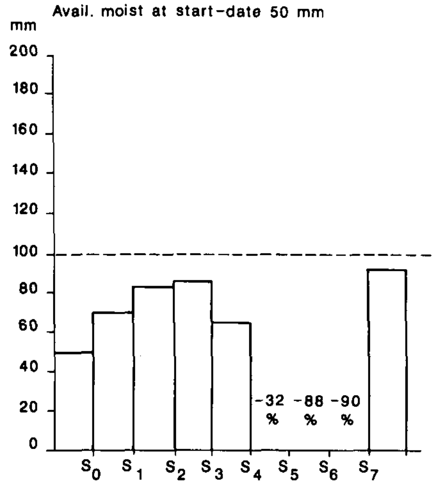


WHEAT

Starting date 1-1

MONTH	D.RAIN	D.EVAP	STAGE	DAYS	KC
J	1.00	1.56	0	15	0.35
F	1.75	2.17	1	20	0.70
M	2.00	2.63	2	25	0.75
A	1.53	3.87	3	45	0.75
M	0.81	5.03	4	30	1.10
J	0.20	6.12	5	35	0.70
J	0.03	6.02	6	15	0.25
A	0.10	5.48	7	179	0.20
S	0.93	4.94			
O	2.00	2.58			
N	2.10	1.79			
D	2.13	1.41			

Soil water budget
Max. storage avail. moist. 100 mm
Avail. moist at start-date 50 mm



Soil water budget
Max. storage avail. moist. 80 mm
Avail. moist at start-date 50 mm

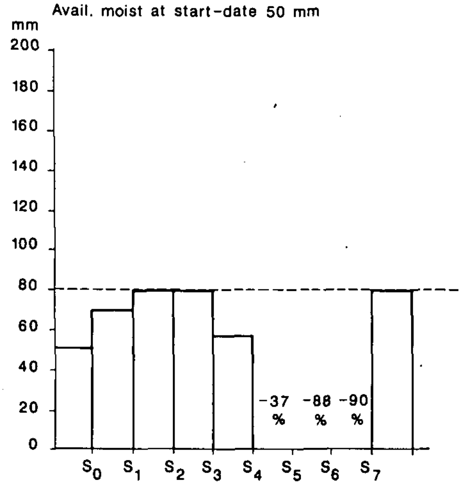


Figure 18.4 Water balance for rainfed wheat in the study area. Severe moisture deficit in the yield formation and ripening stages is common, especially when the crop is sown late. Based on the following climatic data: 50 percent prob.rainfall and potential evapotranspiration according to the radiation method, both for the station Malaga. Stages and crop coefficients according to Doorenbos and Kassam (1979)

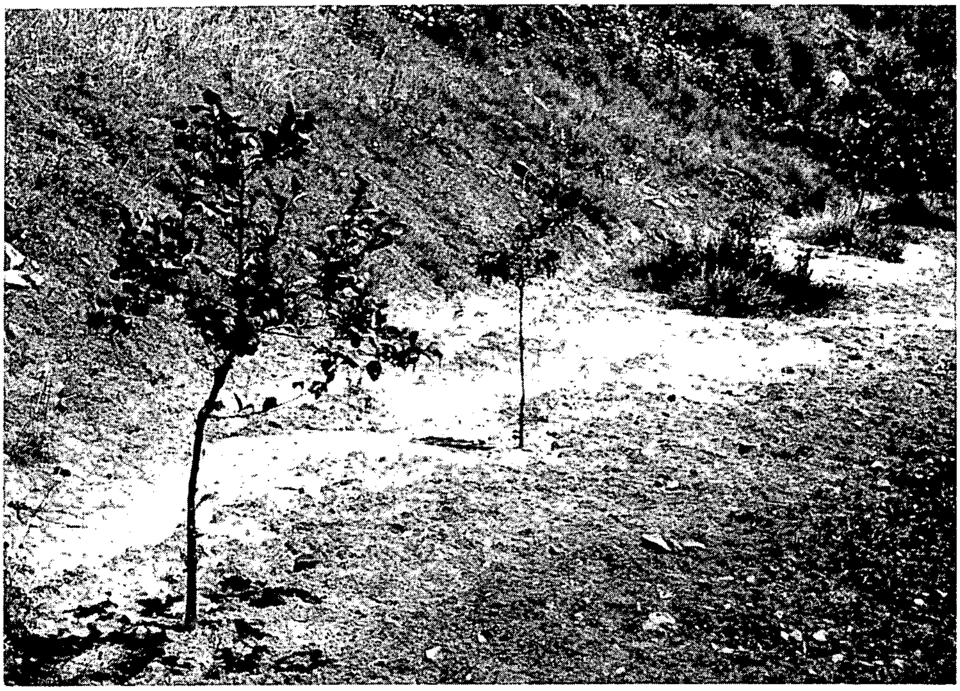


Figure 18.5 Salt crust has formed in the topsoil of a large bench terrace on which citrus is grown. The salinity is concentrated at the foot of the riser where the grey parent material is exposed. Large step heights and poor quality irrigation water (See Figures 9 and 8) are the main causes for this phenomenon. Note the poor stand of the citrus.

declined in this period. In the bench terraced areas the aforementioned problems were aggravated due to poor design of the terraces which induced local salinization of the soils especially in the heavy clays of the F landscape. (Figure 18.5) Poor design of certain terraces furthermore caused drainage and stability problems in the winter period. (Fig. 18.6)

18.4.2.1 The water shortage

The water requirements for citrus according to Doorenbos and Kassam (1979) are during the irrigation season (May/September) 0.65 x the potential evapotranspiration. This amounts to about 4 mm/day during this period. With traditional irrigation methods the 'on-farm' irrigation efficiency cannot be more than 65-60% (Hoare et al., 1974). Mantell (1974) even quotes a U.S. figure of 44%. This means that even a supply of 4.9 mm will not be sufficient. Poor quality irrigation water will aggravate the situation further. As such it can be concluded that under the present circumstances irrigation intensity under traditional gravity irrigation is not sufficient to provide for optimal production. Lemon trees carrying up to 4 generations of fruit-probably indicative of drought-induced flowering, were frequently seen.

Figure 18.6 'Bench terrace effect' in the stand of the citrus. The tree row at the foot of the riser performs very poorly due to exposure of impermeable parent material. The middle row is better than the third row is good. This effect was noticed on almost all bench terraces in heavy soil materials. The effect is more marked with increase in step height.

Another way to arrive at the average amount of water available for the evapotranspiration of the crops is to depart from the estimates for the entire scheme. The average amount of water supplied during the summer months amounts to about 4 mm/day assuming 100% irrigation efficiency. Taking into account the conduction losses and the on-field irrigation losses, this amount will have to be lowered to 2-3 mm/day.

The water quality problem is illustrated in Figure 18.7 which shows the decline of the irrigation water quality during the 1982 season. The water quality in May can be characterized as C_3-S_2 (high salinity hazard medium alkalinity hazard); this is lowered to C_4 S_3 (very high salinity hazard, high alkalinity hazard) in September (according to the classification of US Salinity Lab. Staff, 1954).

Soil solutions with a salinity equal to such waters lead according to Doorenbos and Kassam (1979) to yield reductions of citrus varying from 10 to 25%. Since the salinity is concentrated in the soil, yield depressions of citrus much larger than the aforementioned ones have to be expected.

18.4.2.2 The bench terraces in the study area

The terraces are made without central planning according to the specifications of the individual landowners.

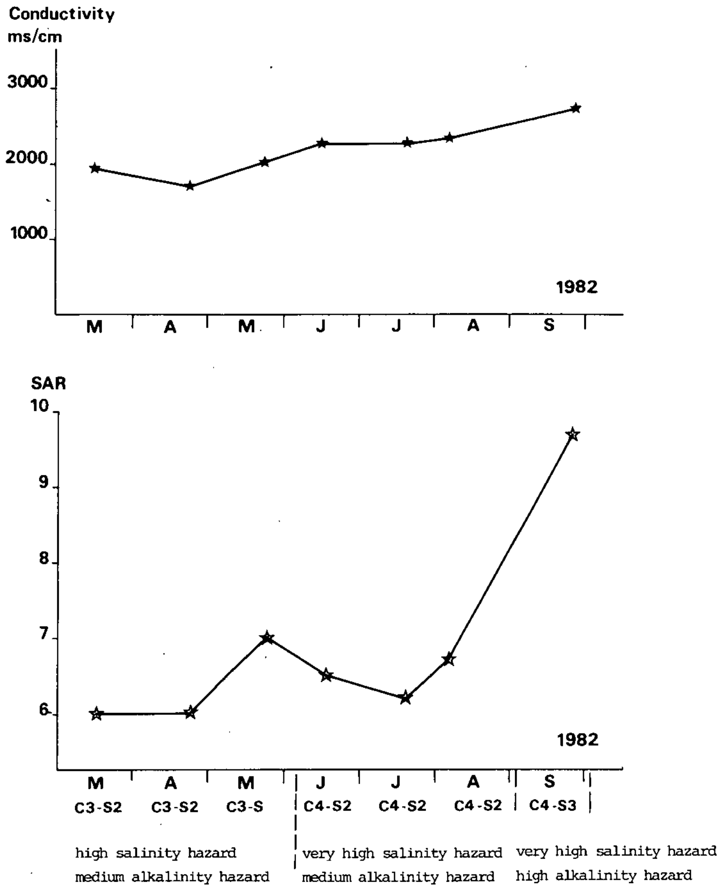


Figure 18.7 Graphs illustrating the decline of the water quality during the 1982 irrigation season. Several dry years had diminished the quantity of good quality irrigation water in the barrages and made admixture of poor quality saline water inevitable. No field observations for 1982 are available.

The following remarks can be made about the terraces in general; (see Figures 18.8 and 18.9) as compared with the recommendations of FAO Bulletin 30 (Constantinesco, 1976):

- In order to get large terraces which make efficient farming and irrigation operations possible, step heights far in excess of the recommended maximum of 1 m, are chosen especially in steep terrain. This has the following consequences:
  a. Degradation of the soil profile and exposure of raw parent material in large parts of the terraces.
  b. Locally the winter groundwatertable may be intersected by the terraces leading to grave drainage problems. In the summer capillary contact with the groundwater is maintained in the deepest parts of the terraces leading to salinization.
  c. Requirements for cut and fill which exceed the FAO specifications by a factor 3 to 6! (1,250 m^3 to get 1 ha of level land (FAO) versus 3,750-7,500 in the study area.

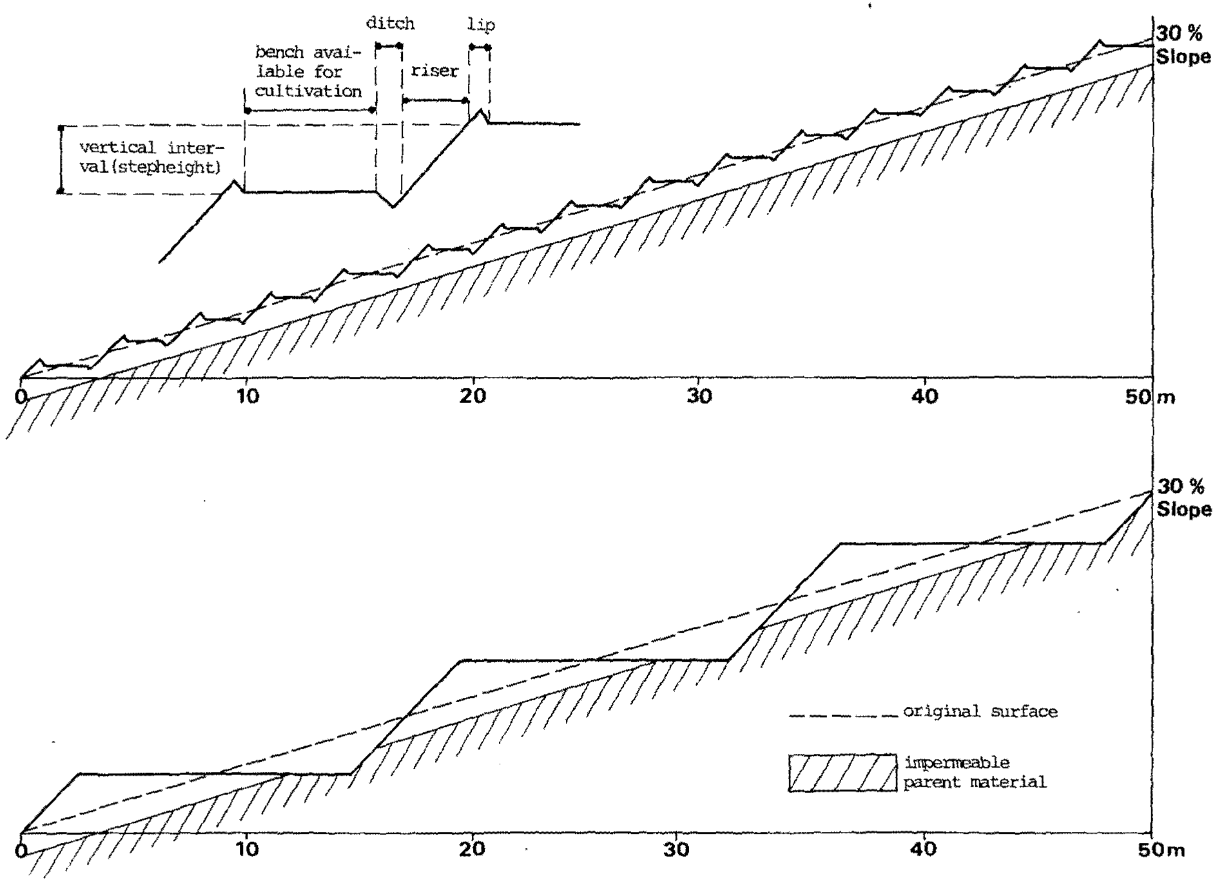


Figure 18.8 Cross sections of bench terraces on a 30 percent slope. The upper drawing shows the bench terraces if made according to the specifications of Constantinescu (1976): step height of 1 meter, riser at 45°, lip and ditch. The lower drawing shows the bench terraces commonly encountered in the study area: height of 5 meters, riser at 45°, no ditch and no lip. Note the intersection of the parent material at a depth of 1 meter by the large terraces. For technical details see the underlined figures in Figure 10.

Bench terraces designed according to FAO (1976)
(1 m vertical interval; riser at 45°)

Slope of land (%)	5	10	15	20	25	30	35
Width of benches including ditch and lip (m)	19.00	9.00	5.67	4.00	3.00	2.33	1.86
Idem excl. ditch and lip (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
Number of benches per 100 m of slope (projected on a horizontal plane)	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 including ditch and lip per ha (%)	95	90	85	80	75	70	65
Idem excl. ditch and lip /ha (available for cultivation) (%)	92.5	85	77.5	70	62.5	55	47.5
Area of riser without ditch and lip per ha (m^2)	707	1414	2121	2828	3536	4243	4950
Idem incl. ditch and lip /ha (m^2)	919	1838	2758	3667	4596	5515	6434
Volume of cut per ha of bench terraces (excl. ditch) (m^3)	1187.5	1125	1063	1000	937.5	873	813
Idem incl. ditch (m^3)	1192	1135	1077	1020	963	903	847
Slope area of riser per ha of benches (m^2)	744	1571	2495	3535	4715	6061	7692
Idem incl. ditch and lip (m^2)	994	2162	3559	5253	7354	10027	13545
Volume of cut per ha of benches (no ditch) (m^3)	1250	1250	1250	1250	1250	1250	1250
Idem incl. ditch (m^3)	1270	1335	1390	1457	1540	1642	1783

Bench terraces as they are commonly found in the study area
(5 m vertical interval; riser at 45°; no ditch and lip)

Width of benches available for cultivation (m)	95	45	28.3	20	15	11.6	9.3
Total width of bench terraces (m)	100	50	33.3	25	20	16.6	14.3
Number of benches per 100 m slope	1	2	3	4	5	6	7
Maximum depth of cut (m)	2.35	2.25	2.10	2.00	1.85	1.75	1.60
Area of benches available for cultivation (per ha), (%)	95	90	85	80	75	70	65
Slope area of riser per ha (m^2)	707	1414	2121	2828	3536	4243	4950
Volume of cut per ha of bench terraces (m^3)	5937.5	5625	5315	5000	4687.5	4365	4065
Slope area of riser per ha of benches (m^2)	744	1571	2495	3535	4714	6061	7692
Volume of cut per ha of benches (m^3)	6250	6250	6250	6250	6250	6250	6250

Figure 18.9 The tables gives the specifications of Constantinescu (1796) for bench terraces for different slopes compared with specifications commonly encountered in the study area. To facilitate comparison between the two sets of specifications, the upper set has been split in a version with and without ditches and lips.

- The slope of the risers of the terraces is frequently in excess of the 45° recommended as a general rule for unsupported structures. This is done in order to eke out more cultivable area from the slopes. It leads often to instability and failures are frequent especially in the impermeable clays with Vertic properties. (Figure 18.10)
- Since the terraces are constructed purely for the purpose of introducing gravity irrigation for the summer months, the conservation aspect of these terraces which is important in the wintermonths, is neglected. This means that no drainage system as specified by FAO is provided while the sides of the terraces are not protected by a 'lip' against over-topping drainage. These measures are probably omitted since they reduce considerably the amount of cultivable area. (See Figures 18.8 and 18.9)

18.5 Drip irrigation an alternative to improve soil and water conservation

Since the 60's various alternative methodologies for gravity irrigation have been introduced. Sprinkler, drip, (trickle) microsprinkler, subsurface trickle etc. These methodologies aim at improving the irrigation efficiency (from aforementioned 44% to 90%) and/or cutting down on labour and operating costs. Especially systems that aim at distributing the irrigation water in carefully measured amounts at short intervals to the root system of plants and not to the field in general (trickle or drip surface and subsurface systems and microsprinklers) fulfil both the aforementioned requirements.

Figure 18.10 Landslide in the riser of a large bench terrace on heavy clay. The Vertic properties of the clay cause instability of the risers in the moist winter season. Steep risers accompanied by large step heights cause this phenomenon.

Numerous experiments have shown the superiority of trickle/drip irrigation in this respect over other irrigation methods:

Bester et al.(1974), Uys (1974), Davis and Pugh (1974), Marsh et al. (1974), Aljibury et al. (1974), Rodney et al. (1977), Gerard (1974).

18.5.1 The water savings

- Water is supplied to the root zone of the plants and not to the soil in general. Losses due to surface evaporation and transpiration by weeds are prevented. This is especially important for young crops which cover only a small part of the field.
- Water is carried to the spot where it is used by means of plastic tubing which means that the on-farm losses can be cut to less than 10%.
- Water can be dosed so precisely that seepage losses even on coarse permeable soils can be prevented by using low dosage-high frequency. The same applies for runoff losses on steep soils with low intake rates.
- The water use efficiency under drip irrigation is higher than under other forms of irrigation. This means that the amount of marketable product produced per unit of water supplied is in general higher for drip than for any other system of irrigation. This is due to the following factors: (Rawitz and Hillel, 1974).

  A high matric potential is maintained continuously in the root zone.

  The absence of moisture stress in the plants produces higher yields.

  The flux of water to replace the uptake by the plant roots depends in general on the unsaturated permeability. Under drip irrigation the permeability is higher since the soil is not allowed to dry out.

  Due to the high concentration of roots in the upper layer under drip irrigation, the flow path of water and nutrients towards active roots is strongly reduced. This means that there is less delay between the application of the irrigation and the effect of it.
- Irrigation waters which are unsuitable or marginally suitable for irrigation with conventional practices can be used profitably in drip systems as experiments by e.g. Bernstein and Francois (1973) and Tscheschke et al (1974) have shown. Wadleigh and Gauch (1948) showed that matric potential and osmotic potential are additive in their effect on plant growth. This means that water of low osmotic potential (saline water) can be used profitably by plants if it is offered to their roots at a high matric potential. Frequent well-dosed drip can do this and thus make irrigation with low quality water profitable.
- Accumulation of salt in quantities harmful to roots will take place under drip irrigation as well as under conventional irrigation practices but the drip irrigation, if properly managed, will keep the salts out of the root zone of the plants.

  Salts will accumulate as a bubble shaped body around the margin of the wetted soil volume. They can be kept there indefinitely (perennials) or have to be leached periodically e.g. winter rain if row crops of annuals are involved.

  The amount of salt introduced into the soil under irrigation is in first instance a function of the amount of water applied. As such, drip uses less water and brings less salt than other irrigation methods. Periodic leaching may be required under both systems. This leaching can be postponed under drip irrigation to the most favourable season however.

18.5.2 The advantage in saving labour and cutting installation- and management-costs

- Drip irrigation makes levelling of fields such as is necessary for gravity irrigation largely unnecessary.
- Labour is saved since the system can largely be automated and can be used to distribute fertilizers, micronutrients, pesticides and herbicides as well.
- Since interrow spaces do not receive water the weed control in these areas does not pose a problem in the dry season.

18.5.3 Disadvantages of drip irrigation

- Drip systems need very clean waters in order to avoid clogging problems. Filtration is necessary. Mineral constituents can also cause clogging which can be counteracted by the periodic flushing with chemicals (e.g. HCl to dissolve $CaCO_3$). Microsprinklers are less sensitive to these problems than drip emitters.
- Shallow rooting induced by surface drip irrigation causes the buffering capacity of the root zone to become very small which means that the plants become totally dependent on the system. Failure of the system in a critical period may become disastrous. This total dependency on the system for water and nutrients applies specifically in those cases where adverse soil and/or slope conditions dictate high-frequency/low-dosage drip.

18.5.4 Comparison of the cost effectiveness of drip and gravity irrigation systems for citrus in sloping parts of the survey area.

The amount of data collected during the 1984 fieldwork is insufficient to make a detailed cost/benefit analysis of both drip and conventional irrigation systems for sloping areas. An effort will be made however to compare the main aspects of the two options on the basis of the data available. The following points will be considered: Installation costs, irrigation efficiency in relation to yields and labour- and management costs.

18.5.4.1 Installation costs

For the present cost of a drip installation including pumps, filters etc., a local figure was obtained in the order of 200,000 to 250,000 pesetas/ha. This is of the same order of magnitude as a figure of US $800-900 per ha quoted by Uys (1974) for South Africa.

For the cost of preparing 1 ha of sloping land for irrigation by means of bench terraces a general figure of 250,000 pesetas was locally obtained. This figure was verified by data from the Table in Figure 18.10 for a 30% slope and found reliable using data from Agricultural Compendium (Ilaco, 1981) and a locally obtained rate of 9,000 pesetas per tractor hour. On the basis of these data the following comparison can be made for land locally sold at a price of 1 million pesetas/ha:

Cost for obtaining 1 ha of benches on land with a 30% slope (Figure 18.9).

Land: 100/70 x 1,000,000 pesetas	1430,000
Bench terracing and levelling 100/70 x 250,000 pesetas	360,000
	1790,000 Ptas

Cost for obtaining 1 ha of drip irrigated land

1 ha of land:	1000,000
drip installation:	225,000
	1225,000 Ptas

This shows that the real expenses for 1 ha of gravity irrigated land are about 500,000 pesetas higher than the cost of 1 ha of drip irrigated land for the case of a 30% slope. If the more expensive system of terracing is followed in which topsoil is saved prior to the terracing and respread afterwards as illustrated in Figure 18.11, a still larger difference results. Drip systems have at the moment a life expectancy of 10-15 years (rapidly increasing). This means that the drip system can be replaced twice for the cost difference that exists between the installation of gravity and drip irrigation in this particular case.

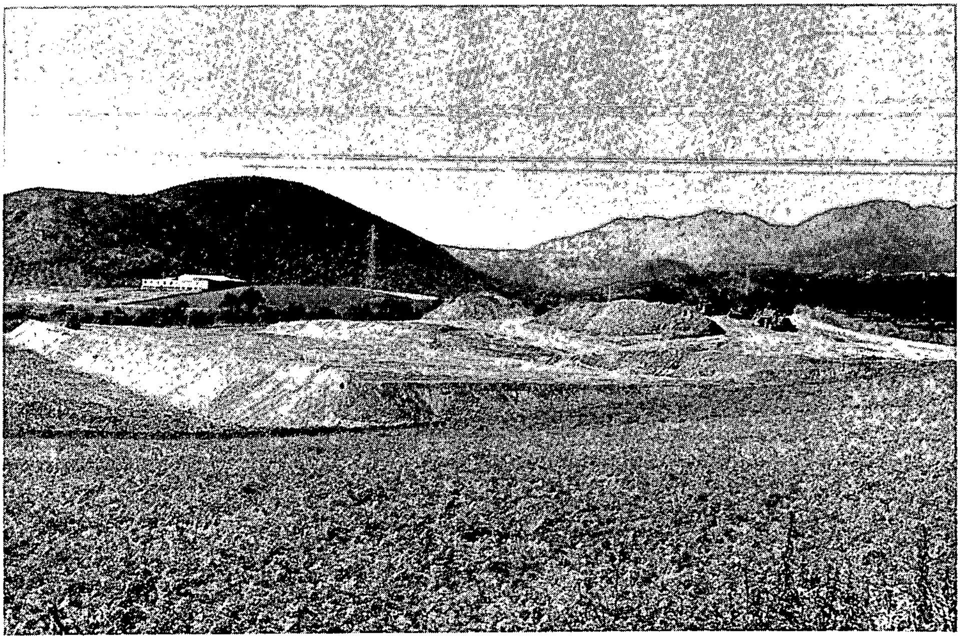


Figure 18.11 Terracing operations in progress for the construction of very large benches. The large step height required to obtain benches large enough for mechanized gravity irrigated agriculture on slopes as steep as 30 percent causes very large volumes of cut and fill (See Figure 9) and requires heavy earthmoving equipment.

18.5.4.2 Irrigation efficiency in relation to yields

The figures given in the preceeding section indicate that drip irrigated citrus uses about half the amount of water that gravity irrigated citrus needs (2 mm versus 4 mm daily) during the irrigation season. In terms of water-use efficiency (amount of product per unit of irrigation water) the following can be computed.
For gravity-irrigated citrus the yields vary from 32 tons/ha (best yield) to 22 (average yield) on Alluvial soils and to 10 tons for bench-terraced citrus on the heavy soils of the F landscape.
These figures lead to the following water-use efficiencies respectively:

6.7 kg/m^3, 4.6 kg/m^3 and 2.1 kg/m^3

If the data (17 ton/ha) of the drip irrigated orchard on sloping Vertisols of F (Figure 18.11) which is not yet in full production are compared to this, a water-use efficiency of 7.1 kg/m^3 results which is already superior to the best orchards in the Alluvium and about triple the figure that holds for the bench-terraced gravity irrigated heavy soils.

18.5.4.3 Labour and management costs

Savings on labour and management costs of the drip system versus the gravity system must be considerable since it was observed (see Figure 18.12) that people laid out drip systems on bench-terraced soils in areas where water was supplied at a fixed rate per ha. The latter implying that their main argument for installing drip must be the cutting of labour and management costs.
Exact data on labour requirements for irrigation operations are lacking for the area. For drip irrigation a figure of one full-time man responsible for irrigation operation, inspection and maintenance per 50-70 acres (22-32 has.) was quoted by Uys (1974).

18.6 Conclusions and recommendations

Most of the data used in this paper have been obtained in interviews with individual farmers. Wherever possible they have been verified against statements from other individuals and against figures quoted in the literature.

As such the order of magnitude of the figures given is considered to be reliable, and justifies the following preliminary conclusions and recommendations for the survey area. Further studies will have to be undertaken in order to refine the conclusions and to add detail to our recommendations. The recommendations take into account that optimum use must be made of the available water, a scarce resource for which agriculture on the one hand and industry and tourism on the other hand compete.

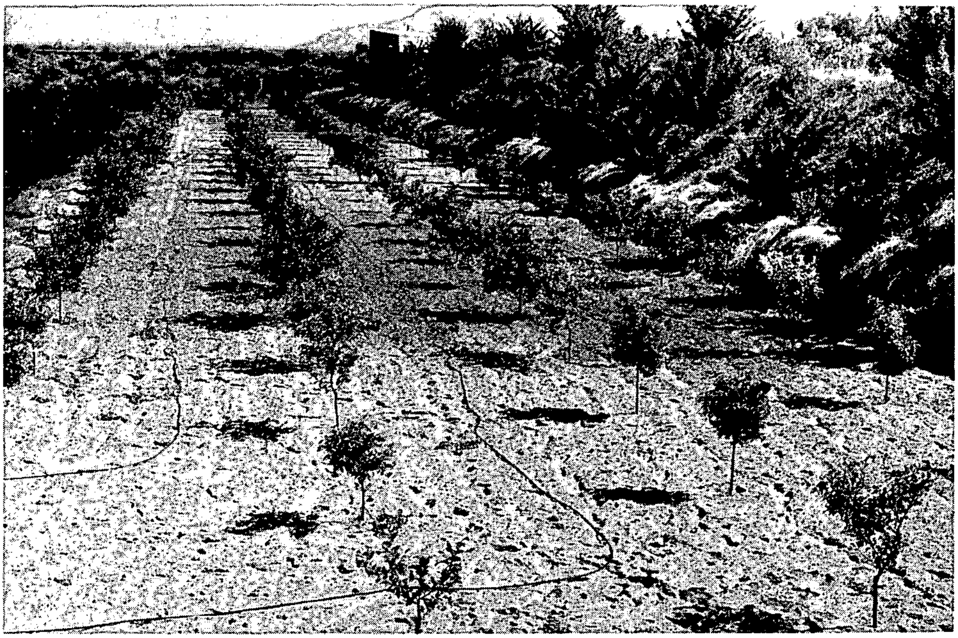


Figure 18.12 Recently planted drip irrigated citrus orchard on bench terrace. The advantages of drip make this system attractive even for people who have already invested in bech terraces for gravity irrigation.

18.6.1 Conclusions

- Rainfed cultivation of cereals on the sloping heavy clay soils of the F landscape is risky and gives in general low yields.
- The construction of bench terraces with step heights larger than 1 m on steep slopes in heavy soils for the purpose of gravity irrigation of perennials causes stability-, drainage- and salinity-problems which have a strong adverse effect on growth and yield.
- Drip-irrigated perennials have a higher water-use efficiency (in terms of kg of produce/m^3 of irrigation water) than gravity-irrigated perennials.
- Drip irrigation of perennials on heavy soils on steep slopes is to be preferred over bench-terraced gravity irrigation in all three of the following respects: soil conservation, water conservation and cost/benefit ratio.

18.6.2 Recommendations

- Bring the subsidies on drip installation on an equal footing with subsidies on measures to prepare the land for gravity irrigation.
- Restrain subsidizing bench terracing operations not performed according to the Guidelines as formulated by Constantinesco, 1976. (More refined specifications ac-

cording to slope and soil can be worked out on the basis of local soil survey results).
- Convert the fixed-rate water charge to a price per unit in order to stimulate water-saving investments.
- Convert the water distribution system to a demand system that allows users to withdraw small quantities on a daily basis for drip irrigation.
- Reclaim terraces with stability, drainage- and salinity-problems by adding a drainage ditch at the foot of the riser and a lip at the top of the riser. Reduce the slope of unstable risers to 45°.
- Convert reclaimed terraces to drip irrigation.

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Appendix 18.1

Soil profile description Site 1

Site information

Profile No.	: 84.04.26
Data	: June 1984
Location	: about 2.5 km Southwest of Alora town, coordinates appr. 36°48′N, 4°44′E
Photo number	: B08, Scale 1: 17,500
Soil Classification	: Entic Chromoxerert
Parent material	: unconsolidated marine clayey sediment of the Paleogene (Flysch)
Landform surrounding country	: dissected plain, undulating to rolling
Microrelief	: plough ridges, on the opposite valley slope various bench terraces are constructed
Vegetation/land use	: olive groove, above the irrigation command, rainfed cereals and pulses
Drainage	: well drained
Moisture conditions	: moist 0-35 dry to slightly moist below 35 cm
Depth groundwater	: unknown
Presence of salt or alkali	: not observed in the field
Human influence	: weeding to conserve moisture by mule-drawn plough

Soil description

Horizon	Depth in cm	Description
Ap	0-15	Yellowish brown (10YR5/6) dry, dull yellowish brown (10YR5/4) moist, clay; weak fine subangular blocky; slightly hard dry, friable moist, sticky and plastic wet; many fine pores; many fine and medium roots; slightly calcareous; pH8.0 clear smooth boundary to
Bw1	15-35	yellowish brown (10YR5/6) dry, dull yellowish brown

		(10YR5/4) moist, clay; strong medium subangular blocky, hard dry, firm moist, sticky and plastic wet; common pores; few fine and medium roots; slightly calcareous; pH8.0; smooth/gradual boundary to
Bw2	35-60	yellowish brown (10YR5/8) moist, clay; strong medium angular blocky; firm moist, sticky and plastic wet; few fine roots; highly calcareous; pH8.5; gradual smooth boundary to
Bw3	60-100	Yellowish brown (10YR5/6) moist, clay; strong medium angular blocky; firm moist, sticky and plastic wet; very few fine roots; highly calcareous; pH8.5; gradual smooth boundary to
BC	100-130	Yellowish brown (10YR5/6) moist, clay; strong medium angular blocky; firm moist, sticky and plastic wet; slightly calcareous; pH8.0; few (Fe & Mn ?) concretions; some powdery light grey (7.5YR8/2) gypsum, smooth gradual boundary to
C	130-150+	Yellowish brown (10YR5/6) clay; firm moist, stickly and plastic wet; slightly calcareous.

Information Site 2

Obs. No.	: 84.04.26a
Data	: June 1984
Location	: about 2.5 km Southwest of Alora town, coordinates appr. 36°48′N, 4°44′E
Photo number	: B08, Scale 1:17,500
Parent material	: unconsolidated marine clayey sediment of the Paleogene (Flysch)
Physiographic position	: close to the rise of a bench terrace, about halfway a SSW facing slope; original slope gradient 27%, altitude 150 m
Landform surrounding country	: undulating to rolling dissected plain
Microrelief	: none
Vegetation	: citrus orchard, strong variation in tree growth due to position on terrace
Drainage	: imperfectly to poorly drained
Moisture conditions	: moist throughout
Presence of salt or alkali	: salt crust presence, strongly saline taste presumably caused by NaCl
Human influence	: construction of bench terraces of 7 m wide, 50 m long and with a rise of ± 5 m

Material

Depth in cm	Description
0-2	White (10YR8/1) saline soft crust,
2-15	light yellowish brown (10YR6/4) clay; structureless; firm moist, sticky and plastic wet; calcareous; pH8.0

Analytical results profile 84.04.26

lab.no.	pH 1:2.5		EC mS/cm	exchangeable cations meg/100 g					CEC	Base sat%	ESP
	H_2O	KCl		Ca	Mg	K	Na	Sum			
84.513	8.6	8.6	24.6	22.0	16.5	0.8	3.3	42.6	16.8	100(254)	19.6
85.514	8.2	7.6	4.7	18.8	15.4	1.1	6.1	41.4	25.9	100(160)	23.6

Lab. no.	Sample no.	Depth cm	Horizon	Particle size distr. (u) in % weight							
				Sand					Silt		Clay
				2000 1000	1000 500	500 250	250 100	100 50	50 20	20 2	⩽2
84.507	1a	0- 15	Ap	0,6	1,1	3,4	8,9	5,8	6,2	13,2	61,0
84.508	1b	15- 35	Bw1	0,9	1,3	2,6	10,3	7,7	4,6	13,5	59,1
84.509	1c	35- 60	Bw2	0,4	1,1	2,6	10,2	6,1	4,7	9,7	65,0
84.510	1d	60-100	Bw3	0,3	0,7	1,5	4,6	2,9	2,7	16,4	70,8
84.511	1e	100-130	BC	0,3	1,4	2,6	4,1	1,9	3,6	14,8	71,3
84.512	1f	130-150+	C	0,1	0,1	0,1	0,2	0,1	1,3	20,4	77,7

pH4 1:2,5		EC2.5	$CaCO_3$	org. matter		
H_2O	KCL	mS/cm	%	C%	N%	C/N
8,1	7,1	0,39	3,8	0,68	0,11	6,2
8,3	7,2	0,37	4,5	0,50	0,09	5,6
8,5	7,3	0,45	6,5	0,20	0,06	3,3
7,9	7,2	2,73	5,1	0,16	0,07	2,3
8,0	7,3	4,30	3,7	0,13	0,08	1,6
8,0	7,0	2,20	4,1	0,16	0,11	1,5

Lab no.	Exchangeable bases in NH4 Ac/A1c (me/100 g soil)				CEC pH7.0	Base sat. %	CEC Clay	ESP
	CA*	Mg	K	Na	Sum			
	29,1	6,0	1,1	0,2	36,4	30,3	100(120)	68,1	0,7
	27,5	6,5	0,8	0,2	35,0	28,4	100(123)	43,1	0,7
	24,5	10,7	0,8	0,9	36,9	27,3	100(135)	42,0	3,3
	33,2	11,1	0,9	1,3	46,5	36,4	100(153)	42,9	4,3
	22,9	16,8	0,8	3,4	43,9	28,4	100(155)	39,8	12,0
	9,4	20,5	0,7	6,5	37,1	31,8	100(116)	40,9	20,4

Lab no.	Clay mineralogy								
	kao-linite	Smec-tite	mi	(illiteiu chlorite)	illite-smectite	sw. chlorite	goethite	feldspar	quartz
	++	++	+				tr	–	tr
	++	++	+				tr	tr	tr
	++	++	+				tr	0-tr	tr
	++	+	+				tr	tr	tr-x
	++	+	+				tr	0-tr	tr-x
	+	+	+				tr	tr	tr-x

Relatively of abundance
+ few
++ moderate
+++ abundant

* error

Resumen

Un levantamiento de suelos semi-detallado fué llevado a cabo en la parte baja de la cuenca del rio Guadalhorce cerca de Málaga en el sur de España de mayo a junio 1984.

El principal tipo de utilisacide la tierra (TUT) de la zona es 'cultivo de citricos bajo riego de gravedad, altamente tecnificado, utilizado en escala media hasta grande'. Este TUT ocupa todos los suelos aluviales planos y está en el momento dispersandose sobre los suelos pesados de las laderas de los valles. En estos últimos lugares forma una alternativa para el TUT 'cultivo mecanisado de cereales en secano a escale media hasta grande'. El problema principal de la agricultura de secano es la baja pluviosidad, y la mayor dificultad del regadío esta ocasionada por la escasesy baja cualida del agua de riegolo cual occurre periódicamente debido a la competencia entre las demandas del turismo, la industria y la agricultura por losescasos recursos de aguas de la región.

El TUT de los cítricos require la construcción de bancales muy largos sobre las pendientes, los cuales permiten el cultivo mecanisado bajo riego de gravedad de este producto. Como resultado de la construcción de tales bancales el perfil natural de los suelos esto siendo destrudo quedando expuesto un subsuelo con propiedades adver-

sas. Este hecho se manifiesta en problemas de drenaje y estabilidad de la pendiente en el invierno, mientras que salinisación occurre verano, affectando seriamente el crecimiento y la cosecha de los citrocos. Un método de riego alternativo el cual no require la construcción de bancales es el goteo.

Se comparan lasventajas y desventajas de ambos sistemas de riego para los suelos pesados pendientes y se presentan conclusiones y recomendaciones preliminares. Estas indican que la introducción del riego de goteo puede ahorrar agua y conservar las pendientes mejor, favoreciendo una cosecha mayor a un gasto de instalación inferior al costo del otro sistema.

Discussion

de Meester: Does not the churning of the Vertisols cause rupture of the citrus roots under intermittent wetting and drying under irrigation?
Siderius: Under drip irrigation a small but significant area around the rootzone is kept moist continuously, therefore the effect of churning is neglectible.

Siderius: Drip irrigation may be beneficial as long as protective measures are being taken even in strongly sloping areas,; if the water can be brought, disregarding the soil-landscape then one introduces a high erosion hazard.

19 Land evaluation and programme planning in sloping areas in North Western Tunisia

D. van Mourik

The views expressed in this paper are entirely those of the author and not necessarily those of the Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH.

19.1 Introduction

Negative effects of rural underdevelopment.
Many predominantly rural areas of continents (e.g. Sahel) or other smaller regions (e.g. provinces) remain undeveloped in comparison to their potential. These regions threaten development of other regions by rural exodus to already overcrowded cities, sedimentation of water reservoirs, etc., creating political turmoil or human misery in- and outside the region itself.

Higher population density requires more intensive land-use system
This process is relatively recent, reaching alarming proportions, caused by too high population densities. These densities have to be retained, because natural regulation of population densities through periodic starvation of people is not acceptable nowadays. Management of these (too) high densities on sustained basis in often more remote areas requires in long term appropriate, but often necessarily, high technology, intensive and sensitive land-use systems, accompanied by monitoring, evaluation and accountancy systems.

Planning and financing of more intensive land-use systems
Rural development projects execute Farming Systems Research. On-Farm Adaptation Research, Extension of Farmers- of Landless People-Groups, etc. to alleviate this situation. It is obvious that continuing subsidies will be necessary from central organizations to conserve sustaining land-use systems in these sparely but often highly overpopulated regions, e.g. in the form of rural development projects.

Intensification of land-use systems by rural development projects
These rural development projects start with a nucleus project. This nucleus project, like a benign virus, affects the farmers of the area with groups of farmers discussing and implementing farming techniques, marketing possibilities, improvement of well being, mining or conservation of agricultural land resources, etc. These groups will in the long term form Cooperatives, Soil- and Water Boards and other special interest groups.

Comprehensive and data processing aspects of RDP's
Most Rural Development Projects have 'Monitoring, Evaluation, Credit and Marketing' to keep track of socio-cultural, ecological and economic operations and impact on these activities. Automatic data processing is thereby an inevitable component to

prevent project personnel and farmers to be tied down in tedious but essential administrative activities. The latter activities diminish the time for more important activities like planning and group-formation of farmer-opinion-leaders, sociologists, ecologists etc.

Local rural development administration
The profile for such a specialist is somebody formed and experienced in land resources survey, development economics, administration and EDP as applied in the working areas of these projects (often remote rural areas). These disciplines are required to monitor the physical, economic and socio-cultural effects of actions using models of verifiable indicators of land and human behaviour.

Summary of this paper
This paper gives an example of programming of a project and an individual farm within a rural development project.
It describes monitoring and evaluation of the level of satisfaction reached by the rural population in one generation (about 30 years)

19.2 Two kinds of programme planning: one of the project and one of the farm

Management Information System (M.I.S.)
Figures 19.1 and 19.2 display an example of the minimum required iterative Management Information System (M.I.S.) and Organization to coordinate the multiple actions of a Rural or Regional Development Project. Figure 19.3 describes the M.I.S. in greater detail.

Agricultural services and rural population
Especially important are the services to customers (= target groups of development actions e.g. small farmers): extension (3) and supply, credit and marketing (5) (Figures 19.1 and 19.2).

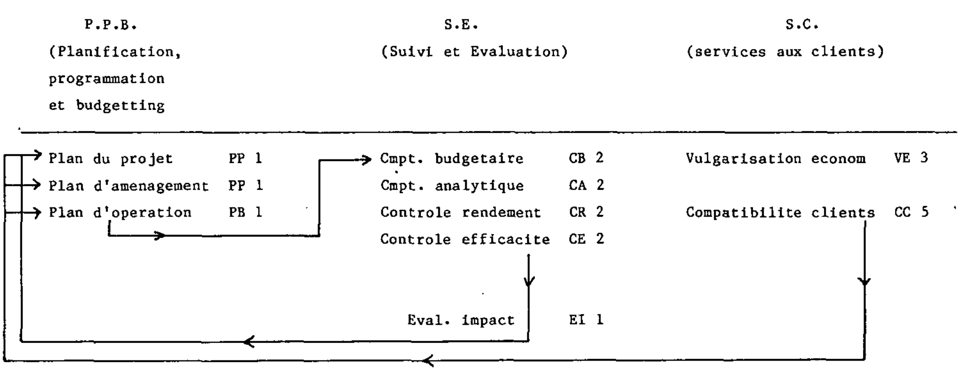


Figure 19.1. S.I.G. systeme d'information de gestion des projects de developpement rural (quoi et comment)

These supply verifiable indicators of income composition, -distribution and -level and participation of target groups. Evaluation of these indicators and the rate of transformation of project-activities into selfhelp groups, cooperatives or soil/water boards enable internal and external project-monitoring.

Figure 19.2 Organigramme de la direction regionale d'un projet de development rural (qui et ou).

finance et comptabilitepersonnel et administration	bureau d'etude	sous direction sejenane	sous direction nefza	sous direction joumine	sous direction tabarka
		Vulgarisation			
		form.inst.rur. prod.animale prod.vegetale activ.feminine Mise en valeur	regisseur magasinier fonds de roulement		
		pistes pont et batiment inst.prairie petit hydraulique economique	chef secteur 1 chef secteur 2 etc...		
		Planif/eval 1 suivi projet 2 informatique 4 appr/cred/comm 5	pistes ponts Inst.prairies		suivi expl.agr. 3

4) Le but de cette section est d'automatiser toutes les gestions de donnees.
N.B/ Pourquoi et quand: voir texte

Impatience of world opinion

This monitoring is necessary since world opinion and literature gets impatient with much intransparent not measurable planning and execution activities of rural development agencies.

Environmental aspects

Next important are environmental aspects as shown for instance in Table 19.1 for the development of primary production of 'macquis' in time for several alternative scenarios and analytical models (see Figure 19.3).

Major improvements

Another important aspect is the sub-division in Project Planning/Evaluation (1) (see Figures 19.1 and 19.2) and Execution activities (2) for the major improvements (Beek, 1978) using external Land Evaluation on one side.

Table 19.1 Model der entwickelung der futterwertpotential projahr von 4800 ha macquis in einige henchirs in sejnane vn 1949 bis 1983.

Jahr (A = model)	1949	1962	1973	1983A	1983B	1983C	1983D
Macquis HA	4800	4557	3685	0	0	635	635
Geroddet seit 1949 HA	–	243	1115	4800	4800	4165	4165
DTO % von 4800 HA	–	5	23	100	100	87	87
Gerodet/periode HA	–	243	872	3685	3685	3050	3050
DTO % von 4800 HA	–	5	18	77	77	–	–
Gerodet/periode/jahr HA	–	19	79	368	368	305	305
DTO % von 4800 HA	–	0,4	1,6	7,7	7,7	6,4	6,4
Installierte prairie HA	–	–	–	–	2000	2000	2000
DTO % VON 4800 HA	–	–	–	–	42	42	42
Garique oder stoppel HA	–	243	1115	4800	2800	2165	2165
DTO % von 3800 HA	–	5	23	100	58	45	45
Futterwert Macquis (400UF/HA)UF X1000	1920	1823	1474	0	0	254	254
DTO Gar./Stopp. (200UF/HA)UF X1000	–	49	223	960	560	433	433
DTO Dauerweide (1600UF/HA)UF X1000	–	–	–	–	3200	3200	–
DTO naturweide (400UF/HA)UF X1000	–	–	–	–	–	–	800
DTO total 4800 HA UFx1000	1920	1872	1697	960	3760	3887	1487

A) Situation ohne project mit in der zeit logaritmisch extrapolierte degradation der vegetation.
B) Situation mit project mit in der ze logaritmischit extrapolierte degradation der vegetation.
C) DTO mit linaeir extrapolation D) DTO mit lineaire extrapolation und verbesserte naturel weide.

Minor improvements

On the other side extension (3) and on-farm production aspects (5) for the minor improvements (Beek, 1978) using internal land evaluation. The latter can generally be executed and financed by the farmer alone or in groups with or without credit.

Programming

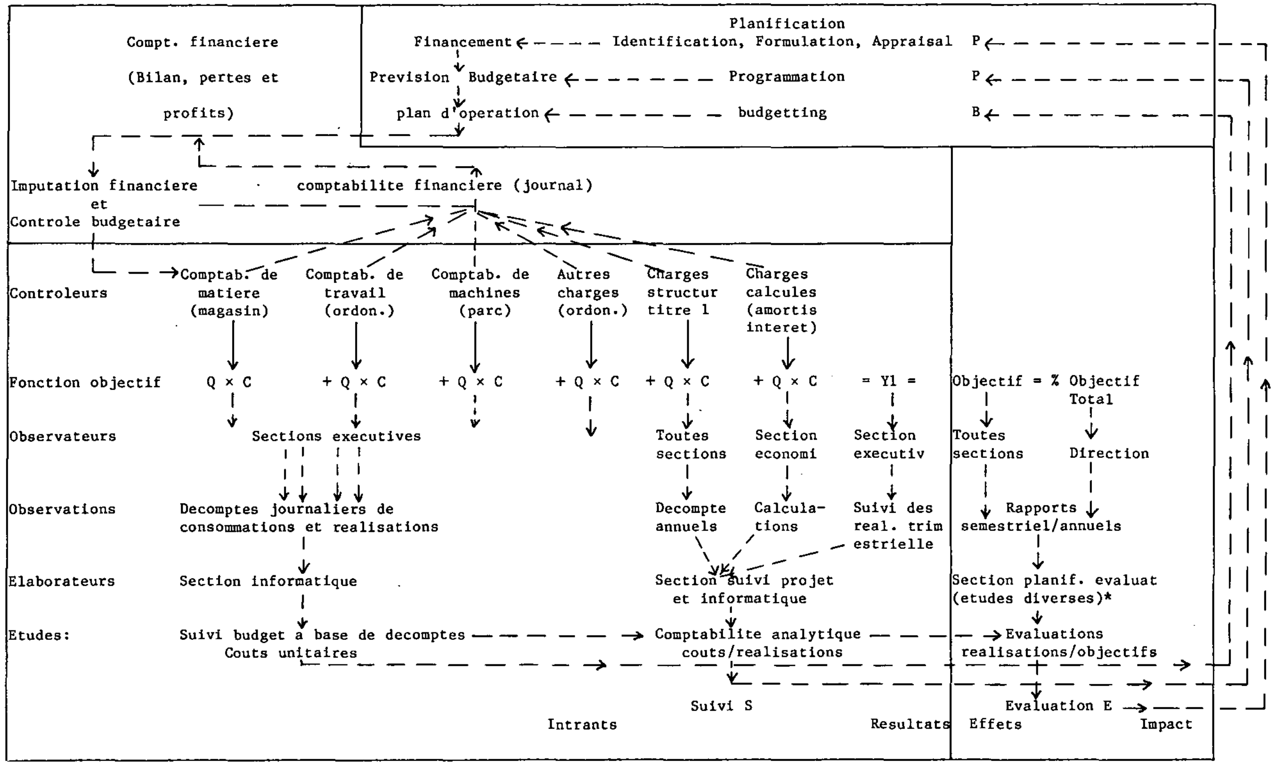
In both cases the Programme Planning phase is of crucial importance and can only be done with thorough knowledge of the local situation by local technicians (initially governmental, later paid by farmer groups) and farmers together, be it for major improvement, e.g. different watershed protection plans of enterprises or LUT's on the farm.

Project analysis without effect analysis

Standard economic project analyses methods are available and well known (Gittinger, 1982) for these analyses, but do not account for effects on different groups (farmers, traders, etc.)

Farm programming

The latter form of programme planning is the one used by farm economists and extension specialists to find the best farmplan. It is only mentioned here to emphasize the preference of its use in rural development projects over linear programming. The latter



N.B. * Documents du fonds de roulement, centre de collecte de lait et la section vulgarisatrice

- - → circuit de documents

⇉ flux des biens

Figure 19.3. Planification, programmation et budgetting; comptabilites, suivi et evaluation des projets regionaux de developpement rural

being too rigid, too difficult and too intransparent for the variable conditions of family-farmers in rural remote areas with often degrading environments and lack of reliable data.

Agro-ecological modelling
Quality of data in land evaluation, their presentation as estimates or in precise terms, their analytic or holistic analysis and degree of accuracy in modelling, somewhere in the continuum of the black box to accurate functional models, are shortly discussed by Van Diepen (1983). In FAO (1984) Radcliffe gives some examples of agro-ecological modelling used for programme planning in a district of Mozambique, while the Agro-ecological Zones project of the FAO is presently engaged in refining its analyses to country-level.

Land utilization modelling
Functional agro-ecological modelling is therefore relatively advanced and not treated in this paper. Missing is often its link with the L.U.T. description in:
a. one production function with;
b. more accurate differentiation of the family farm L.U.T.'s by their differentiated product composition;
c. definition of the needs for the farmer in his area to hold him back from the rural exodus;
d. accurate monitoring of this exodus;
e. inclusion of the production trend of his L.U.T. and f) inclusion of major and minor improvements a capital (needs) in this production function.

Project programme planning
This needs not to be done exhaustively. Van Mourik (1984) has described the framework of studies with participation of the population, needed to collect the necessary data. Below some very rough functions of points a. to f. are described, forming a rough monitoring model.

19.3 Functional models of regional rural development, some simplified functions

Functions of a regional development model.
A model consisting of the above described links (points a. to f.) of agro-ecological functions with agro-economic functions is simplified described below for agricultural development including animal husbandry.
a. the production function:
   Yt = L x T x C with
   Yt = products; L = labour; T = land; C = capital.
b. the objective function:
   Yt = Y1 − I + Yb + Yc + Ya + Ye with:
   Yt = total products; Y1 = milkproducts; I = non factor inputs;
   Yb = 'meat' products; Yc = cash crops; Ya = other agricultural products and
   Ye = external products (salaries, etc.)

c. the needs function:
$N = SMAG + CHRF - AUTOC$ with
N = needs; SMAG = minimum agricultural salary; CHRF = overhead costs and AUTOC = autoconsumption.
d. the population function:
$\Delta LA = (100\,\Delta\,LT - (\%LE/LT)\Delta\,LE)/(100 - \%LE/LT))$ with
LA = agricultural population; LT = total population; LE = population active outside agriculture, Δ = % change.
e. the land function:
T = present value of 15(-30) years of production, as for instance could be calculated in Table 19.1, based on data from El Amami (1976).
f. the capital function:
$C = Ca + Ci$ with
Ca = major improvements (artifactial landqualities like roads, etc.) and Ci = minor improvements (on farm).

19.4 A simplified and imaginary application of a model to the Sejnane Area

Modelling of satisfaction of the population within one generation.
The model of Sejnane is determined by its verifiable indicator: the sold daily milkproduct of some 2,000 farmers as obtained from their electronically processed revolving fund- and milk customer-accounts at the project: (all data are imaginary!)
a. Yt $= Y1 - 0{,}8Y1 + 0{,}7Y1 + 0.1Y1 + 0Ya + 0Ye$
b. N $= 830 + 270 - 200 = 900$ DT (DT = Tunesian Dinar)
c. L $= (-150 - (20x0{,}5)) / 100 - 20 = -2\%$
d. ΔLA $= ((-150-(20)\,0.5))/(100-20) = -2\%$
From a. and c. can be derived that today, e.g. 45% of the population has satisfied its needs. From d. can be derived: an additional 2% per year of the 55% unsatisfied, satisfies itself by finding employment outside agriculture or by migration. The region will thus have satisfied its needs in one generation (55%/2%/year = 28 years).

19.5 Conclusions and recommendations

Rural development project organization.
An M.I.S. and Project organization as presented in Figures 19.1, 19.2 and 19.3, with emphasis on compact, on the site, programme planning for the project and the farm, using external and internal LE, is needed to monitor the L.U.T.'s (e.g. their farm size and – number, influencing the land flight) simultaneously with the L.U.T.'s (degradation and gap between potential and realized production).

Electronic data processed land utilization modelling
This systematic programme planning should use an international multidisciplinary land development-systems-terminology. Simple electronic data processing is necessary to narrow the gap between incomplete planning goals and necessary achievements

of projects and its inaccurate monitoring. This programme planning should be done with simple functional models, based on analytical and holistic analysis, as demonstrated in the paper to simulate more accurately the development based on verifiable indicators.

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20 Land evaluation: a part of the decision environment of the subsistence farmer in the Rif mountains, Morocco

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Abstract

Beni Boufrah is a small (23 x 10 km) valley on the northern flank of the Rif along the Mediterranean coast. The climate is semi-arid, with a highly variable rainfall. The average rainfall is about 300 mm and falls mainly in winter. Human settlement began in the 16th century and has spread gradually over most of the valley. Today, there are about 9,000 inhabitants, living in 21 villages.

This paper deals with the relationships between man and his environment at two levels: the villages (community level) and the farmers (individual level). A problem of the first level is the choice of sites for settlement. Throughout the centuries, people based their decision to settle on a perception of livelihood possibilities in which the requirements of agriculture and proper judgement of soil quality played an important role. This resulted in a specific settlement pattern: for reasons of security, early immigrants seem to have avoided the better soils on the lower flat parts of the valley and to have preferred deep Luvisols on the relatively moist north-exposed slopes.

In one of the villages, five aspects of the decision environment at the level of the individual farmer were investigated: distance to his land, ownership, input of nutrients, input of grain, and land characteristics. It appears that the peasant's strategies are rational within the constraints set by custom and physical environment.

This research needed the integration of physical and socio-economic data. The quality of the various measurements and the difficulties involved in the collection of the data are described and evaluated. The last part of the paper deals with the implications of the man-environment relationships for rural development.

20.1 Introduction

According to the FAO Framework (1976, p.1), 'land evaluation is concerned with the assessment of land performance when used for specified purposes'. In this sense, land evaluation is in the first place the concern of the farmer who works the land. However, according to the Framework and most other publications on this subject, land evaluation is generally seen as a tool for land-use planners. Although the data for defining attributes of land utilization types must include information from farmers, their contribution to the land evaluation procedure as proposed by the Framework is quite small.

De Smet (1961) is one of the few authors who systemized the utilization of farmer's knowledge for land evaluation purposes. He had the advantage of working in an area of highly developed agriculture where he could communicate directly with the local farmers. In developing countries it is more difficult to bridge the gap between land-use planner and farmer. A good example is given by Siderius (1982) of how local soil names in Burkina Faso are indicative of the workability of the soil, its waterholding and infiltration characteristics, and its crop production potential.

One of the land utilization types listed in the Framework is 'smallholder rainfed arable farming with traditional technology' (see also Kostrowicki 1974). This is the land utilization type prevailing in the Rif Mountains. Beek (1975, Table 20.2.5) lists a number of attributes of a similar land utilization type which is described as dry farming/small holding/hand labour and animal labour. It is the purpose of this paper to show that land evaluation by the local farmer concerned with this land utilization type is based upon centuries of knowledge of the ecosystem in which he performs. This knowledge must not be ignored should plans be made for the rural development of this area.

The Rif is one of the main mountainous areas where the 'small farmer is confronted with big problems' (ILACO, 1979). The big problems include scarce and erratic rainfall, erodible soils, steep slopes, fragmented holdings, restricted possibilities for development and rapid population growth (Lentjes, 1980). As a result, agriculture is reduced to a marginal activity which often necessitates the development of additional sources of income. Under these conditions, survival of the individual as a farmer depends on choosing the right farming strategies.

The decision environment of the farmer in any part of the world is composed of elements of an economic, social, personal and physical nature (Ilbery, 1978) . Vink (1975, pp. 235) states: 'Agricultural land use is always carried out in enterprises which are units for economic production under given social conditions; the consideration of economic and social parameters...is essential in land evaluation for agricultural purpose'. According to Wapenhans (1979), a farm at the smallholder level is a social institution rather than an enterprise.

The study of the extreme complexity of the decision-making process requires contributions from several disciplines. There are many difficulties involved in the cooperation of sciences with a physical and a socio-economic signature. They include differences in approach, problems of scale, ways of data acquisition, power of measurements, and methods of interpretation. An important requirement is the selection of a common unit of research, be it a mapping unit, a water well or a farmer's piece of land. If physical, social and economic data are collected on this basis, statistical correlations are possible.

For the investigations in the Beni Bourfrah valley discussed in this paper, spatial units have been selected at two levels of scale: the settlement as a spatial realization of collective decision-making, and the farmer's plot as the spatial realization of individual decision-making. These two levels are also different at the temporal scale. Decisions at the settlement level were taken perhaps centuries ago and have to be investigated with historical methods, whereas decision-making at the farmer's level is a continuous process which must be studied with methods developed in the behavioural sciences.

This paper forms part of a multidisciplinary study of the Beni Boufrah valley carried out by the Laboratory of Physical Geography and Soil Science and the Institute of Social Geography of the University of Amsterdam in cooperation with the 'Institute Agronomique et Vétérinaire 'Hassan II', Rabat. The aim of the project was the analysis of the socio-economic conditions of an area which has been left by many of its inhabitants to come to work in Europe. The main outcome of the project was reported by Pascon & Van der Wusten (1983). Most arguments presented in this paper have been derived from De Mas & Jungerius (1980) and Jungerius et al. (1985).

20.2 The Beni Boufrah Valley

The Beni Boufrah valley is representative for the many valleys of the Central Rif along the Mediterranean coast. It is fairly small (23 x 10 km). The relief descends from an altitude of about 1,600 m in the south, towards sea level in the north. The underlying rocks are flysch, consisting of alternating marly shales and sandstones (Maurer, 1968). The river, also called Beni Boufrah, has a broad, gravelly riverbed or oued which contains water only for very short periods after heavy rainfall.

Human settlement began in the 16th century. Before that the valley appears to have been empty for some time. The settlers were driven from Spain by the Reconquista or came from surrounding parts of the Rif which were overpopulated or unsafe due to feuds. It was not an easy land to live in. Apart from the physical difficulties of the climate and the terrain, there was the easy access from the sea which facilitated all sorts of raids by pirates (Braudel, 1966) which made living in this valley rather dangerous. Since 1550, the population has increased to about 9,000 inhabitants spread out over somewhat more than 20 villages ('douars').

Each douar has its own territory (Figure 20.1). It consists of a built-up area, irrigated fields, dryland arable plots, zones with trees (mostly almonds), rough pasture, complete waste land and forest. There is a rather clear consensus among present inhabitants about demarcations between douars but no administrative recognition. A claim of the government on the forest contradicts the traditional rights of the local population.

The valley can roughly be divided into three landscapes: a mountainous zone with much mass wasting in the south, a hilly one of erosional slopes in the middle of the valley, and a zone of pediments (glacis) and valley flats which begins halfway along the valley and increases in width towards the north.

Part of the zone of mass wasting is under forest. Most of the remainder of the valley is in agricultural use, with extensive grazing of the fields farther removed from the settlements. The inhabitants are well aware of the soil and land properties in this area which they indicate with specific terms. In fact, local names are generally related to well-defined parts of the landscape which form the mapping units of the soil survey (Pascon & van de Wusten, 1983):

- level and undulating hill ridge areas ('dhar', back or 'ras', head). These parts are relatively productive if not deforested too long ago;
- steep slopes ('amalou', shadowy and relatively moist when exposed to the north; 'assamar' if exposed to the south) with brown stony soils which wear the coulter ('ferriche'), shallow soils on calcrete ('habyad') or rock outcrops ('troucha') and relatively deep red soils ('hamri') on north-exposed slopes which have better moisture conditions than other slopes;
- level areas at the base of the steep slopes extending to the centre of the valley ('oulja', 'mer'). These are pediments covered with reddish slope material ('hamri').

The best conditions for agriculture are provided by the 'hamri' on north-exposed slopes and on the pediments. The soils on these slopes are Calcic Luvisols (FAO/

UNESCO, 1974) with a reddish argillic horizon and a well-developed calcic horizon. They offer ample space for plant roots and hold water well because of the clayey texture and blocky structure. Calcaric Fluvisols are formed in the slope deposits on the pediment. Added to the favourable properties of the Calcic Luvisol, they suffer no erosion and the level terrain is easy to work.

The average annual rainfall is about 300 mm, with much variation between the years. In years with a regular rainfall in the growing season (October to April), falling in quantities sufficient to cover crop needs, it is possible to grow barley and even wheat on dry land. But in many years one of the agroclimatic requirements is not met and the crops fail: the animals are allowed to eat what little there is on the fields before harvest time, or there is no growth at all. The ratio of good: moderate: poor years is 35:45:20 (Pascon & Van der Wusten, 1983).

20.3 Problems of data acquisition

An evaluation of the variables describing man-environment relationships have been discussed by Jungerius et al. (1985). It is important to observe these relationships over longer periods in order to discern longterm trends. However, it is impossible to find the necessary data for obvious reasons: human settlement and its concomitant resource management have not been recorded over long time periods. This data problem cannot adequately be solved. It can only be circumscribed by estimates and the use of variables chosen on the basis of deductive reasoning.

To test the assumption that the early settlers were guided by their awareness for environmental conditions when choosing a site for settlement, it is important to know the dates at which the various parts of the valley were occupied by settlements. The only way to acquire this knowledge was by genealogical reconstructions based on oral interviews of inhabitants, backed up by written documents from local family archives on property and marriage contracts, and controlled by general historical information. This provided a list of approximate foundation dates of the settlements that was thought to be sufficiently reliable. These dates stretch out over a period of more than four hundred years (Figure 20.1).

Apart from the difficulties in determining the boundaries of the present settlements, two additional problems arose. There is no way of knowing the stability of the present divisions. The territories of the douars may have waxed or waned over time for demographic, political or other reasons. The second problem is that land use has changed in the course of time. As long as there were only a few villages, much of the land was used as collective of all Beni Boufrah to move herds controlled by a few people on a seasonal basis over larger distances. Later on, more and more of this land was permanently settled and the new villages demarcated their own territories. The collective area became ever smaller until the settlement pattern reached its final form at the beginning of this century. At present only a small part remains at the outer edges of the valley.

A problem met during the research in Joub, the village where individual decision-making was studied, was the selection of land characteristics which control the peasant's decision environment (De Mas & Jungerius, 1980). Clearly, not all attributes of the land are directly related to agricultural production. There are also considerations

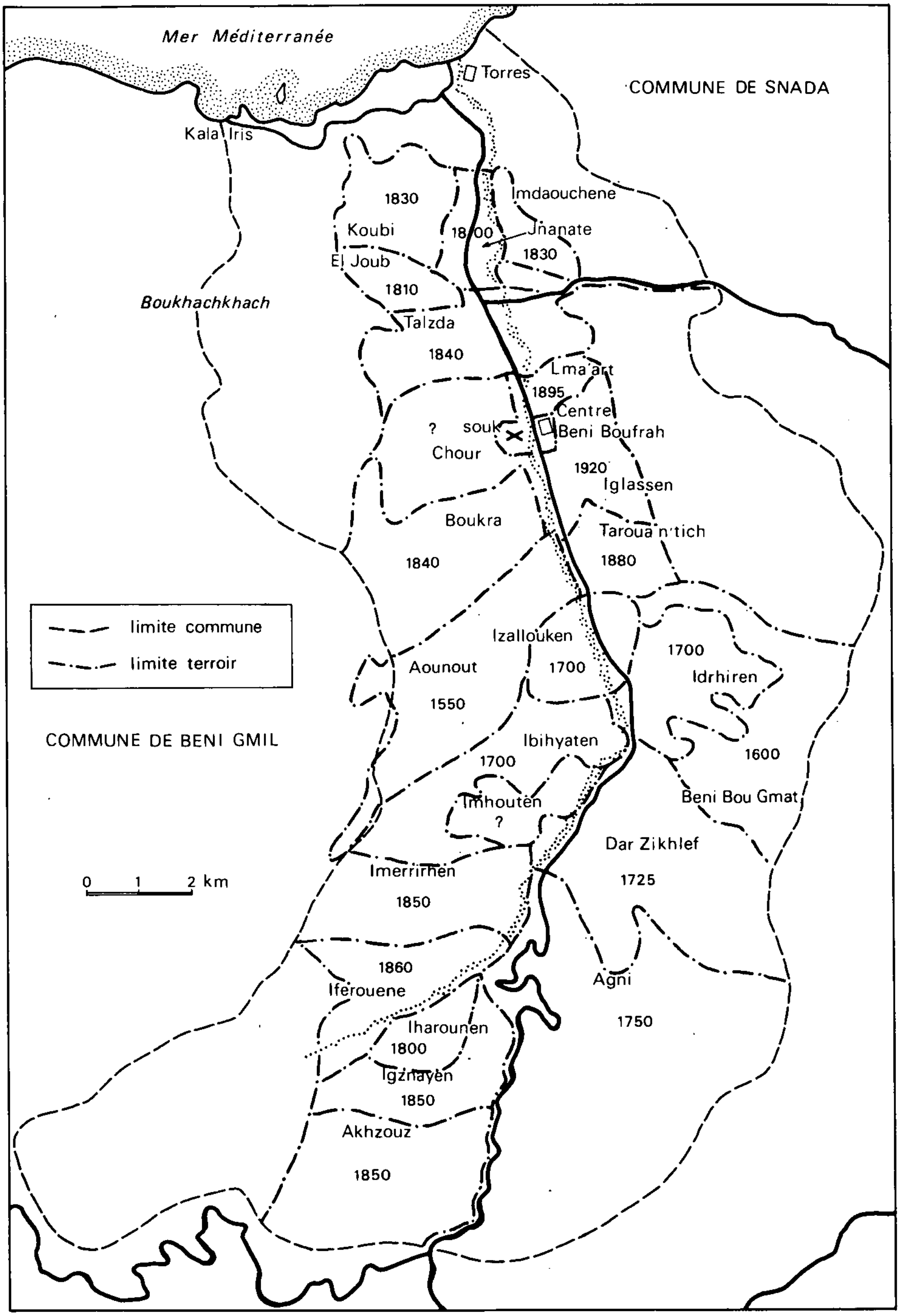

Figure 20.1 The villages of the Beni Boufrah and their year of foundation (from: Jungerius et al., 1985).

of another nature, like feeling of security, or sense of familiarity brought about by ownership during several generations. The variables used for the correlation analyses have been selected on the basis of oral interviews. These interviews are hampered by the fact that the rationale of his actions may not always be clear to the farmer. Some of these actions seem to be dictated by custom and represent a collective wisdom acquired in century-long dealings with a hostile environment.

A major generator of noise in the quantitative processing of the data is the weakness of the measurements. The farmer estimates the size of his land not by surface but by days of plowing. For Joub, 4 days of plowing roughly represents 1 ha. The input of manure is measured not by tons but by number of baskets. He estimates the quantity of seed by the number of times he has to fill the hood of his djalaba which he uses to carry the seed across the land. Such data are best processed with nonparametric statistics (Siegel, 1956).

20.4 Decisions at the community level

Two factors of the decision-making process pertaining to the choice of settlement sites were investigated in the Beni Boufrah valley,: security considerations and agricultural conditions (Jungerius et al., 1985). In times of insecurity, accessibility to the villages should be minimized. This can be accomplished by siting the villages as far as possible from the sea and from the oued which has long been the central axis of communication through the valley.

The best conditions for agriculture are offered by the Fluvisols on the pediments and along the oued. In the hills the best soils are those on the rounded ridges and the Luvisols on north-exposed slopes. In a situation where man's decisions are controlled by the quality of the environment, these soils should have preference.

In Table 20.1, the 21 villages are grouped in 2 x 2 matrices according to their attributes having below or above average values. These averages are 1,790 AD for year of foundation, 11 km for distance from the sea, 1 km for distance from the oued, 43 ha for area in the hills occupied by above-mentioned better quality soils, and 70 ha for area on pediments and along the stream.

Table 20.1 Number of vollages in the Beni Boufrah valley, in relation to varous physical attributes and age.

	date of foundation	
	before 1800	in or after 1800
distance to sea < 11 km	0 villages	9 villages
distance to sea > 11 km	7 villages	5 villages
distance to oued < 1 km	3 villages	7 villages
distance to oued > 1 km	4 villages	7 villages
area of Luvisol <43 ha	4 villages	9 villages
area of Luvisol >43 ha	3 villages	5 villages
level area <70 ha	2 villages	11 villages
level area >70 ha	5 villages	3 villages

It appears that most of the older villages were founded rather far removed from the sea in the relatively safe hilly zone. Although it is not readily apparent from the table, the older settlers also avoided the flat parts near the oued: the oldest villages were founded 2.2 and 2.7 km from the oued. It means they could not make use of the superior soil conditions in the level terrain. However, in the hills where they made their living they knew how to find the best soils for agriculture.

20.5 Decisions at the farmer's level

The village of Joub is situated about 3.5 km from the sea. There are about 300 inhabitants belonging to 33 households, 28 of which have access to land. Of these, 26 are actively engaged in farming. Their houses are built close together in the village (Figure 20.2). The group of farmers is fairly homogeneous; there is little social and economic stratification within the village. The average size of a farm is about 3.5 ha, divided over to 14 fields. The distance to these fields is up to 5 km. All 164 fields were visited by the team of investigators in the company of the farmer.

For each plot, 5 aspects of the peasant's decision environment were determined: distance to his land, ownership, inputs of nutrients, inputs of grain, and land characteristics.

The influence of distance to the fields is best explained by a modification of the well-known Von Thünen model. The theoretical background for this specific case is explained in De Mas & Jungerius (1980). In this model, the use to which a piece of land is put depends on the distance from the village where the farmer lives. The intensi-

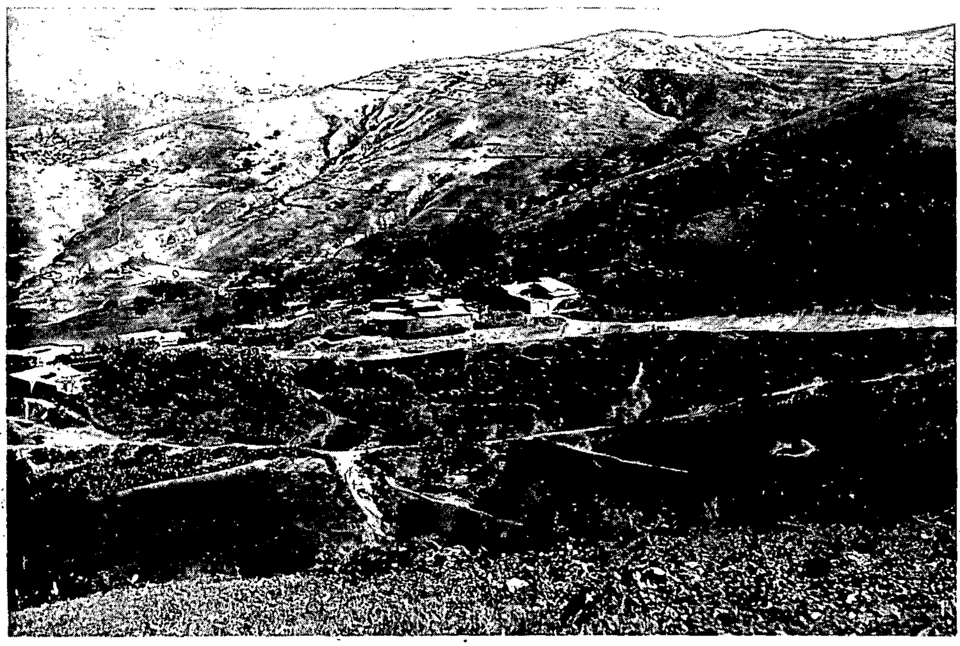

Figure 20.2 The village of Joub.

ty of land use diminishes with distance, even in circumstances where the quality of land improves at a greater distance (Tarrant, 1974, pp. 31). For the purpose of this research, the plots of lands have been divided into two groups. The plots of the inner zone are situated in a topographically well-defined area of roughly 1 by 2 km around Joub. The plots of the outer zone are scattered over distances up to 5 km.

Ownership is another important variable. Part of the soil around Joub is owned by the peasants, part is controlled by some sort of tenancy arrangement. The farmer is generally inclined to take better care of land that he owns. Nutrients are added, if at all, in the form of manure ('akhbar') or artificial fertilizer ('engri' from french engrais). The latter type is clearly less favoured perhaps because it spoils the taste of the food in the farmer's opinion.

There is little variation in cropping pattern from year to year. Out of the 164 parcels of land, 128 were sown in with grain crops in the year of investigation (1978), the remainder being in fallow or used for other crops. Of the two types of grain crops, barley is preferred to wheat, partly for cultural reasons, partly because it is better adapted to the adverse conditions of the environment.

On each peace of land, seven characteristics were estimated or measured which are related to agricultural productivity: organic matter content, stoniness, soil depth, rock outcrops, workability (a combination of texture, structure and consistency), slope steepness and slope exposure. A plot of land was considered 'good' if its score was positive on 4 or more of these characteristics.

From Table 20.2 it appears that the land-use pattern around Joub is to a large extent an expression of these 5 aspects of the farmer's decision environment. The following general conclusions can be drawn:

– Much of the land in the immediate surroundings of Joub is of poor quality. This

Table 20.2 Number of fields in Joub, relation to varous attributes and inputs.

distance		central zone	external zone			
quality of land		good	poor	good	poor	total
property	manure	24	33	5	1	63
	fertilizer	2	4	13	7	26
	no input	0	1	7	1	9
	total	26	38	25	9	98
lease	manure	1	4	1	0	6
	fertilizer	10	2	13	2	27
	no input	1	2	9	2	14
	total	12	8	23	4	47
property	barley	17	31	15	4	67
	wheat	3	4	9	4	20
	total	20	35	24	8	87
lease	barley	5	2	12	3	22
	wheat	7	4	8	0	19
	total	12	6	20	3	41

cannot be helped because many plots of land are sloping, worn out and eroded, and inherited from the ancestors of the present inhabitants. In this zone there is a strong preference for barley which is better adapted than wheat to the poor soil conditions, makes a better bread than wheat according to the local taste, and can be used as fodder. The farmer is well aware of the poor condition of his land: he tries to remedy this with the input of manure. As a result of his care, the soils here are often more productive than those of better physical quality in the outer zone.

- The strategy chosen for the outer zone is quite different. Here, the land is commonly in tenure, but whether in tenure or not, it is clear from Table 20.2 that the peasant knows how to select the best pieces of land for his purpose. Input of nutrients, if at all, is in the form of artificial fertilizer and preferentially reserved for land of good quality and held in ownership. Much wheat is grown here, especially on land in lease. This could be partly obligatory on the part of the landlord.

20.6 Implications for rural development

Efforts to raise the agricultural productivity in the Beni Boufrah valley should take into account the implications of the man-environment relationships discussed in previous paragraphs. Disregard of this principle would probably have destructive effects on the village communities, but may also lead to rapid deterioration of the natural resources. The latter effect can be illustrated with the comparison of local and government efforts to check soil erosion which was made by Jungerius et al. (1985):

It is difficult to prevent sheet wash of arable land on the relatively steep slopes where the soils are bare for most of the year. Still, the farmers are reasonably successful in slowing down the process by a number of measures. These measures appear to be traditional elements of the agricultural practices: the soil is tilled by donkey- or muledrawn ploughs along the contours; inherited plots are divided by the sons along lines parallel to the contours; stones and rocks removed from the field are dumped along the lower field boundary where they form low stone walls which induce terracing.

The actions of the government are much more evident in the landscape. Many of the steep slopes have been terraced and planted with almond trees. The terraces were dug at regular intervals without consideration of the erosion hazard. From a soil conservation point of view, they are a failure. They have been cut into the impermeable subsoil and collect water at the surface at times of rain. As there has been no maintenance, the terraces are now breached at places of overflow of the collected water which induced new gully development.

An important point concerning tradition 'which plays an important role in all land utilization types, particularly agriculture' is made by Vink (1975, pp. 238): 'Tradition in agricultural land use is largely the result of accumulated and integrated practical experience of past years and past generations. Experience therefore always plays an important role and, seen in this light, traditions in agricultural land use are extremely useful means of transferring knowledge and experience through the successive generations of farmers. To some extent, therefore, tradition is a healthy corrective against unwarranted sudden changes in land use which 'cause disruptions resulting in grave hazards for the agricultural population as well as for its lands, and therefore for a country' (op.cit. pp. 239).

At the village level, it is tempting to direct agricultural development efforts at the flat land on the pediments and along the streams. Apart from offering the best conditions for crop growth, soils here are not affected by erosion. In fact, deposition of relatively humic material eroded from the slopes improves the quality of the soils here. It has been suggested by various investigators of comparable situations (De Ploey, 1984; Mensching, 1985) to allow soil erosion to continue on slopes and concentrate agriculture on lower slopes where the colluvium is deposited.

Such a policy would not work in the Beni Boufrah area. Although the level parts of the valley indeed offer the best possibilities for development, their surface in the middle and upper parts of the valley is limited in extent. Not all villages have land in this zone and even if they have, it is accessible to only a restricted number of farmers. Preferential development of these parts would seriously upset the socio-economic relationships in the village community. Therefore, the agricultural use of the sloping lands remains important for the people of Beni Bourfrah.

At the farmer's level, it seems feasible to advise concentration of his efforts on the superior land farther away from the village which react favourably to the input of manure. However, there are several reasons why the farmer is not in a position to follow such advice:

- The amount of available manure is very limited. This problem cannot always be solved by artificial fertilizers in view of the costs and the resistance against its use. At the subsistence level, this is a serious impediment to an increase of production.
- Intensive use of the fields in the outer zone requires transport which is not or insufficiently available. The distance is also an obstacle to adequate weeding which is traditionally done by the women. Furthermore, crops on far fields cannot be properly guarded against theft.
- The time/space constraint plays an important role in the farmer's decisions at the time of sowing. The best time for sowing is the period immediately preceding the onset of the rains (Arnon, 1972). However, the farmer is not able to break the soil which is hard at the end of the dry season, because he has no access to sufficient traction. The time available for plowing and sowing is restricted to a few days after the initial rain. Within this time the farmer tries to till as large an area as possible. This will accentuate the use of the fields nearby where he loses little time for transport.

The removal of such time/space constraints should be one of the main objectives if rural development in the Beni Boufrah valley is considered. These and all other efforts to solve the problems of the small farmers here should fit in the ecological framework outlined above.

Acknowledgement

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Discussion

van Diepen: Was there a relation between period of settlement and soil depth; how was the original soil depth estimated and how was the rate of truncation measured?
Jungerius: We tried to find a deposit on the basis of which to correlate the land-use history and the rate of erosion by means of pollen analysis (a technique successfully applied in Luxembourg); however we did not succeed as the climate is not suited for the conservation of pollen; what we used was the extend of the exposed calcic horizon or petrocalcic horizon for each settlement.

van Mourik: The study covered 20,000 ha, can the results be extrapolated to a larger area to aid in rural development?
Jungerius: The study was not funded by the Dutch Bilateral Aid Organization but by ZWO (Foundation for Scientific Research); this was done on purpose as the researchers did not want to give straight-forward advice but felt the need to study the problem first; an ecological approach was used as each area has its specific problems;

from the physical point of view there are many similar valleys in the northern rif and the settlements may also be roughly similar; thus the basic conditions may be similar for a larger area but the outcome for the farmer will differ from farm to farm.

Lindstrom: The paper holds many important messages for the workshop; one is that good communications with the farmer must be established before any conservation works can commence; thus knowledge of the local language is important.
Jungerius: It is difficult to obtain reliable information in the area as the population does not like the afforestation programmes because their land is taken away; also women must be interviewed by women, for this purpose girl students from the University of Rabat were involved.
van Vliet: Did you find any relation between gully formation and lenght in time, so that the volume of soil taken away could be estimated?
Jungerius: Gully formation was not studied in depth; to obtain an idea about soil loss Stocking's method for Zimbabwe was used, giving a correlation between length and depth of gullies and the calculated soil loss.

Working group reports

In addition to the working group themes, the eight questions raised by K.J. Beek in his opening address were discussed when applicable.
These questions are:

a. Will it be useful, in enhancing multi-disciplinary cooperation, to prepare guidelines for land evaluation, not only in connection with major kinds of land use, but also in connection with specific problem- land situations, such as the sloping land areas?
b. How can land evaluation include the interaction between different land-use systems linked within one sloping landscape by the same hydrological cycle?
c. How can land evaluation make explicit recommendations for the short-term and for the long-term?
   Here, experiences from developed countries, where long-term policy in the conservation of natural resources is under high pressure from short-term vision, will be relevant.
d. If there is a future for computerized land information systems in sloping areas, what effect will this have on data collection, updating of information, and monitoring?
   Should these systems be site-specific?
e. Since the framework for land evaluation distinguishes between land and use, how can the functioning of the integral eco-system be evaluated without a too-arbitrary sub-division into sub-systems? This question is of particular importance where long vegetational cycles, such as protective forest, are concerned.
f. Especially for conservation, how can the immaterial functions of natural reserves be included in the land evaluation procedure?
   This may be of great importance in, for instance, the conservation and use of tropical rain forests.
g. How do the different mapping scales affect the purpose and procedures in land evaluation?
   Adherence to specific mapping scales may avoid some confusion during the discussions.
h. I should appreciate suggestions for future activities of the ISSS Working Group on Land Evaluation. Personally, I should like to organize a joint workshop on 'Land Evaluation and Land Information Systems' with the Working Group on Soil Information Systems.

Working Group 1: Inventory of land characteristics regarding erosivity, relief, erodibility, present and past erosion in relation to land use and erosion hazard.
Chairman: M. Stocking Secretary: A.C. Millington

The conclusions, numbered 1-14 which arose as a result from the discussion are:

1. Data requirements for inventory are dependent on the survey scale and planning needs.

2. Erosion inventory can be divided into two types:
   (a) inventory for broad-based erosion hazard, and
   (b) inventory for field-scale sustained resource use.
   Both types of inventory need to consider on-site and off-site benefits.
3. Physical and socio-economic parameters can be defined as the two groups on which data needs to be gathered at both scales.
4. Depending on what is available, soil type or land systems data can be used, but, initially, a bare-surface should be considered.
5. The important climatic factors for water erosion are rainfall amount, intensity, and temporal distribution. Rainfall intensity can be extrapolated over large areas using equations which relate rainfall amount to intensity, or daily intensity can be calculated by the ratio of monthly rainfall amount to rain days, where a range or probability distribution can be specified.
6. Land systems data encompasses important hydrological parameters relating to sediment routing in the landscape and relief parameters such as slope length and shape. Slope angle data can readily be collected as a separate parameter.
7. Antecedent soil moisture data is covered by climatic and soil type data at the broad-based scale.
8. Land cover types, mapped from multi-temporal satellite imagery over a year, need to be considered with canopy cover measurements from ground survey to provide vegetal cover indices for the main land cover types in any area.
9. Land utilization types (LUT's) provide a methodology for collecting much socio-economic data relevant to erosion risk. The most appropriate method for data collection would be well-structured computer-compatible field data sheets.
10. 'Static' inventory maps of erosion status and 'dynamic' inventory maps of erosion hazards are needed. Erosion status maps can be produced by mapping current erosion phenomena using remote and ground-based techniques. They provide a benchmark by which erosion hazard maps can be considered. Erosion hazard maps will rely strongly on physical processes and LUT alternatives, and they can be used to:
10. (i) assess the efficiency of conservation policy on 'erosion black spots', and
    (ii) indicate new 'black spots' when different LUT alternatives are considered.
11. Data needs to be collected, stored, and retrieved in information systems; well-produced automated grid maps provide the most cost-effective method of data presentation.
12. The minimum (basic) requirements in any area are:
    (i) slope data (angle, roughness, length of slope)
    (ii) infiltration data
    (iii) rainfall data (particularly intensity)
    (iv) soil information (particularly depth and profile characteristics)
    (v) sealing susceptibiltiy.
13. Observations need to be made on cultivation systems and the determinants on the land-use decision-making processes (viz: social, cultural, economic attributes).
14. A standardized check-list of basic parameters by soil type and farm should be used to collect data, including additional locally-important data. Data should be stored in data banks that can provide different data sets, depending on end-user requirements.

Factors required for inventory, data handling, and presentation from inventory.

Broad-based inventory	Small-scale inventory for sustained prediction
Physical factors	
1. Soil types or land systems data	1. Slope angle, length, roughness, and shape data
2. Rainfall amount, intensity, temporal dist.	2. Rainfall intensity data
3. Slope angle data	3. Soils information (particularly depth and profile characteristics)
	4. Infiltration data
	5. Sealing susceptibility
Socio-economic factors	
4. Land cover types and vegetal cover indices	6. Cultivation systems
5. LUT's	7. Cultural, social, economic factors affecting land-use decision-making processes.
Types of maps	
Erosion status and erosion hazard (static) (dynamic)	Erosion status (static) and conservation planning (dynamic) erosion hazard (dynamic)
Data handling and presentation	
Use of computerized geo-based information systems; grid maps	Field check sheets (basic requirements and additional data); data bank storage, conservation plans.

The following remarks are made concerning some of the questions posed by K.J. Beek. Reference to the numbered conclusions is given in parenthesis.

a. Inventory must be designed with multi-disciplinary cooperation in mind (3),
c. Broad-based erosion status and hazard assessments imply longer-term perspectives (1, 2),
d. Computerized information systems are essential to handle, store, and present data in broad-based erosion inventories (11),
f. Nature conservation can be considered as an alternative LUT in a broad based-erosion inventory (9),
g. The scale division is a functional division affecting the purpose and procedures of land evaluation (1, 2), h. A workshop on 'Land Evaluation and Information Systems' is fully supported.

Working Group 2: Monitoring land transformation (degradation and conservation) by teledetection.
Chairman: L.P.J. van Vliet Secretary: H. Huizing

The discussion is summarized as follows:

1. Monitoring was defined by the group as 'observing changes of conditions over time and relating these to the processes that cause the changes'.
2. Monitoring should center on changes and processes that lead to substantial soil losses and associated decreases in productivity that are likely to occur within a time span of a few generations up to about 100 years.
3. The main aim of monitoring is primarily for the maintenance of the resource base and then for improvement of the resource base. Results of monitoring can be used as an input in dynamic models in order to verify and/or adjust such models.
4. The first step in the design of a monitoring programme is the identification of 'areas of concern' or key areas. This identification is preferably done on the basis of an existing land inventory.
5. Within the areas of concern, land-use system (LUS) changes that (might) lead to land degradation, if any, should be detected and followed in time. LUS changes may include:
   - changes in LUTs and/or their key attributes
   - changes in land characteristics

6a. The following LUT and key attribute changes need to be incorporated in a monitoring programme:
   a. LUT changes that lead to a substantial change in land cover (seasonal or permanent)
   b. changes in cropping systems (cropping pattern, land rotation, etc.)
   c. changes in farm management, i.e. the use of labour, capital and technology; cultural practices, land tenure
   d. changes in infrastructure
   e. changes in production/yields

6b. Changes in land characteristics that require monitoring are:
   f. changes in erosion phenomena
   g. changes in erosion control works
   h. changes in vegetation composition

6c. The information on the above mentioned changes should be complemented with:
   i. measurements of rainfall characteristics
   j. measurements of soil losses from plots
   k. measurements of sediment yields (as an indicator of the combined soil loss from different LUS in a catchment)

7. Monitoring methods and techniques include:
   I comparison of existing land and land-use inventories of different dates (when available)
   II comparison of available air photo coverage of different dates
   III sequential information based on interviews and/or secondary data
   IV sequential satellite images
   V special purpose aerial photography, for instance sample strips obtained from a low-flying aircraft

VI systematic field observations and sampling
VII continuous field measurements
VIII combinations of I to VII

8. Methods I, II, and III generally make change detection possible. On the basis of these methods, problem areas that require more detailed and more frequent observations can be identified.
   Methods III to VII can be applied in such areas.
9. The combination of methods chosen depends on the changes/processes to be monitored, on the (detailed) aims of monitoring programme, and on local conditions.
10. Monitoring programmes will be carried out by:
   - local operators (not beneficiaries)
   - regional/national (government) institutions
   - international organizations

Comments on the questions 'a' to 'h' posed by K.J. Beek by Working Group 2.

a. Specific land problem situations must be dealt with in the context of a broader, overall land evaluation of an area. Where such problems occur, the land evaluation team should avail itself of the appropriate expertise in the problem field. The working group therefore prefers improving the existing guidelines for major land-use types rather than preparing new guidelines for problem situations. Improving may include updating, expanding and/or annexing the existing guidelines. Considerations with regard to monitoring should be included.
b. Land evaluation provides alternatives for land use to planners without taking decisions on desired LUS. The indication of positive and negative interactions between suitable LUS should be an integral part of the land evaluation, however, particularly in the case of ecological interactions. 'Scenarios of selected LUS' based on land evaluation results should be viewed in the context of formulating a watershed management plan before implementation is started. Monitoring applications and results must be taken into account in the formulation of such a plan.
c. Monitoring land transformation requires short-term information for medium to long-term prediction, planning, and action.
d. A computerized land information system will make it easier (i) to handle sequential, area-specific data obtained by monitoring (ii) to relate changes/processes to other data available for the same area.
e. The revelance of this question for the monitoring of land transformation is restricted.
f. Attention should also be given to the monitoring of land degradation in 'natural' areas. The same applies to the monitoring of their areal extent, which in many countries is rapidly diminishing.
g. The map scale should be related to the purpose of the monitoring. In monitoring, the spatial resolution of the available teledetection techniques may also play a role.
h. A workshop on 'land evaluation and land information systems' is highly relevant considering the rapid development of the technology for the handling of geographic data in the last few years. Aspects of monitoring should also be handled by this workshop (see comments on question 'd').

Working Group 3: Land-use systems and their actual and potential land cover.
Chairman: A. Young Secretary: W. Siderius

The importance of land cover is recognized, especially with regard to the interaction of the effects that various land-use systems have on soil erosion. An assessment of the mineral land cover may include size and frequency of coarse fragments, while canopy height and percentage leaf cover are relevant for organic land cover.
The questions 'a' to 'g' were addressed as follows:

a. This question leads to a recommendation that guidelines for erosion hazard assessment and conservation planning should be prepared within the existing guidelines; in doing so, the role of the farmer must be emphasized, while a multi-disciplinary approach is needed.
b. The scale on which the assessment is carried out is important; extrapolations from on-site to off-site effects are needed but should be done with great care. Within a watershed the concept of land evaluation units may be useful.
c. The interaction of activities is recognized, thus it is not realistic to separate the short-term from the long-term objectives.
   The short-term objectives pertain in the first instance to the farmer, while the long-term ones embrace future generations.
   This leads to a recommendation that practices of soil conservation are balanced against level of production, e.g. measures must take into account sustained yield on a socially equitable basis.
d. The working group recognizes the need for land information systems and emphasizes that data collection should be less artistic; LIS should not be site specific.
e. The functioning of an integral eço-system can be evaluated by means of natural (= meaningful) subdivisions.
f. As to the evaluation of immaterial functions of natural reserves (gene poles), the working group recommends the identification of LUTs especially concerned with nature conservation. However, the priorities of local governments with regard to development objectives must be respected.
g. With regard to mapping scale, due conservation is given to working from small to large scales with a recheck of the former; the complexity of land mapping units is recognized. It is concluded that the purpose of land evaluation governs the map scale and not vice versa.

Working Group 4: Modelling interactions between land use in catchment areas.
Chairman: D.E. McCormack Secretary: P.M. Driessen

The working group discussed simulation techniques for land evaluation with particular reference to sloping lands.
Discussions centered on:

1. The applicability of framework principles and concepts in quantitative land evaluation
2. The role of land characteristics and land qualities in the quantitative analysis of erosion hazards and conservation needs

3. The scope for applying modelling techniques to support decisions in Land-Use Planning
4. The most desirable strategy for quantitative land evaluation
5. Types and data requirements of models in relation to the purpose and scale of the analysis
6. Data acquisition and management
7. Contacts with other thematic groups within ISSS.

Conclusions and recommendations of the working group are worded as follows:

ad. 1 The WG concludes that the principles and concepts put forward in the Framework for Land Evaluation are a sound basic for modelling the productive capacity of land.

ad. 2 The WG concludes that the concepts of land characteristics and land qualities play a pivotal role in the simulation of erosion processes and conservation needs.

ad. 3 The WG concludes that modelling techniques can play a significant role in land evaluation to support conservation of land- use planning.

ad. 4 The WG concludes that a promising strategy for quantitative land evaluation comprises the following steps:

1. The clear delineation of land and utilization type boundaries within which the system under analysis operates.
2. The analysis of the physical processes governing the productive capacity of land. Crop and land management are an integral part of this analysis.

The subsequent analysis of socio-economic and other conditions and processes that influence the suitability of land.

ad. 5 The WG concludes that 3 main categories of land evaluation models can be distinguished that differ in scope, target (client) group and data requirements:

1. Macro-models aimed at natural resource management at a continental or local scale.
2. Regional models that supply central and regional government bodies with a policy-tool for regional development.
3. Detailed models at village, farm or field level for use by farmers (organizations), extension services, etc.

The WG recommends that methodological work on process-oriented analytical models be promoted as such models help to identify critical knowledge gaps and further understanding of the structure and dynamics of the processes which determine the permanent productive capacity of land. It also facilitates the development of stochastic models with clearly defined boundary conditions for practical application.

ad. 6 The WG concludes that a central agency for coordination of data acquisition and data quality control is required. ISRIC would be qualified to undertake this role if adequadely funded.

ad. 7 The WG concludes that there is a need for strong interaction of model and data base development. The WG recommends that a joint meeting of the ISSS working groups on Land Evaluation (LE, Subcommission C) and on soil information systems (DP) be held for that purpose, preferably in 1985 or 1986.

Working Group 5: Land suitability based on resistance to erosion and other land qualities.
Chairman: A.B. Mitchell Secretary: A. Weeda

The conclusions of the working group are:
1. The land evaluator must obtain a clear understanding of the requirements of the user within his planning framework in relation to feasibility in order to obtain the maximum benefit of the evaluation process.
2. The land evaluation must be considered as a politically independent, technical, and socio-economic tool. In the process, all relevant disciplines should be included.
3. The responsibility of the land evaluator is to follow up his work as far as possible in association with land-use planners or decision-makers.
4. It is of importance that local staff should be involved in the land evaluation process in order to secure continuity of use of land evaluation results for land-use planning.

Working Group 6: Implementation of soil conservation measures based on land suitability assessment.
Chairman: K.W. Flach Secretary: D. Palin

The subject was discussed under the following headings:
1. Involvement of the farmer
2. Establishment of an institutional organization
3. National policy
4. Communication

The following conclusions are drawn:

ad 1. Involvement of the farmer.
- a. A survey of the farmer's knowledge of farming and conservation practices is necessary.
- b. Discussion, and agreement on, the conservation plans with the farmer before implementation is advocated.
- c. Financial government support for the farmer for the implementation of conservation works must be considered.
- d. The organization of joint programmes, especially in areas dominated by smallholders, enhances the implementation of soil conservation works.
- e. Integration of conservation and extension services should be promoted; soil conservation goes 'across' farm boundaries.

ad. 2. Establishment of an institutional organization.
- a. The need is felt for integration with other conservation and development programmes. This could be realized through an organization which incorporates and coordinates other government departments like agriculture, forestry, livestock, water, etc.

ad. 3. National policy
- a. The need for a national policy and strategy is evident in many countries.
- b. There is also often a need for a national body which is responsible for conservation, inclusive of planning and training.

ad. 4. Communication.

a. Land evaluation through local government is advocated as communication is easier at lower levels; to increase communication, the need for training in land evaluation procedures is stressed.

Working Group 7: Social and economic aspects of land conservation; priority needs of small farmers.
Chairman: D. Palin Secretary: D. van Mourik

Considering the eight questions raised by K.J. Beek in the context of social and economic aspects of land conservation and priority needs of (small) farmers, the working group recommends that:
the multidisciplinary approach apply to all phases of the work, from initial investigations, through diagnosis to problem solving.
In the discussion the working group stressed the following points:

1. The main social disciplines which should be included are:
   a. demography,
   b. economics (agro-, micro-, communications, and political economy),
   c. anthropology (social, cultural),
   d. sociology.

These disciplines should be combined with those of the physical scientist and the practical disciplines of the farmers

2. Types of analyses:
   a. historical analysis of all disciplinary aspects is essential for an understanding of the situation,
   b. analysis should take account of the social, economic and physical dynamics,
   c. these analyses should predict to what extent the potential socio-technical system will be capable of offsetting existing and predictable rates of degradation.
3. Scientific and management approaches.
   It is important to compare and reconcile the viewpoints of land managers (e.g. farmers) and outside experts, concerning both individual and community needs and physical resources needs, in order to arrive at acceptable interventions.
4. Decision takers.
   The land evaluation clients are the following groups who allocate different kinds of resources:
   - politicians,
   - farmers and their spouses,
   - civil servants,
   - local government officials (traditional and modern),
   - bankers and financiers.
5. Team
   In achieving a multidisciplinary approach, the working group thought the following points were important:
   a. the terms of reference should pose multidisciplinary questions,
   b. sufficient time for teambuilding should be allocated,

c. work procedures (e.g. investigation methodology, report writing) and physical arrangements (e.g. location) should support the holistic approach,
d. the teamwork of the outside experts should be apparent to the clients.
e. teams should take advantage of work locally done (e.g. using 'ICRAF, diagnosis and design' or CIMMIT techniques).

Closing session

Anthony Young

ICRAF, Nairobi

This Workshop forms part of a series of discussion meetings which began at Wageningen in 1972. That occasion first brought together scientists active in rural land development, to share their experience and seek a common outline of procedures. They had found that the mere survey of natural resources, as in soil survey, land systems survey or various ecologically-based approaches, was not enough. The mapped resources had to be compared with the requirements of land use. Following further meetings in Rome, the text of the Framework for Land Evaluation was published (FAO, 1976). This took as its guilding principle, that land suitability is assessed and classified with respect to specified kinds of use.

The Framework has since been extensively tested in field applications, and used as the basis for training in land evaluation. The general approach and concepts have proved remarkably resilient, able to stand up to a wide variety of applications. It is a relatively slim volume, however, and one reaction was a request for more specific details on procedures. Such details vary from one kind of land use to another, and this led to the preparations of sets of guidelines related to major kinds of land use: on rainfed agriculture (FAO, 1983), forestry (FAO, 1984), irrigated agriculture (FAO, in press) and extensive grazing (in preparation). Guidelines for agroforestry are at an early stage of preparation (Young, 1984).

The present Workshop differs from this pattern, being directed not at a specific kind of land use but at a type of land. Originally conceived in problem-oriented terms, as land evaluation for erosion assessment, this was felt to be restrictive, and broadened so that all aspects of land evaluation applicable to sloping areas could be included. A consequence has been a certain dichotomy of aim during the meeting. Sloping lands have but one feature in common, moderate to steep slopes; every other land characteristic can vary ---- they can be wet or dry, hot or cool, possess acid or alkaline soils, and so on. Moreover, sloping lands can be developed for crop production, forestry, livestock production, agroforestry or recreation and conservation. Hence papers related to any land quality, on drought hazard for example, or tolerance to acid soils, could not have been ruled as irrelevant to the topic in hand.

But the important land qualities in any particular sloping area are X, Y, Z and erosion hazard, where X, Y and Z could be anything, so many papers rightly concentrated on erosion hazard assessment. Yet, as was shown, there can be a substantial water erosion hazard on some very gently sloping lands; and if we are treating water erosion hazard, why not cover wind erosion as well, which can take place on totally flat areas? This duality of aim, environment-oriented and problem-orientated, was never wholly resolved.

Let me turn to the three themes of the meeting:

The application of the FAO Framework, the assessment of erosion hazard and conservation needs, and applications to land-use planning.

That the approach and procedures of the Framework should form the basis for land evaluation was never seriously questioned. The method of soil potential assessment, developed in the U.S., was shown to be not only compatible but to some degree parallel with the Framework in its procedures; a feature of interest was the emphasis on participation of potential users in the construction of the evaluation. The approach of diagnosis and design, devised by ICRAF for agroforestry but potentially applicable to other kinds of land use, is certainly not similar in concept to the Framework, but then neither is it attempting to do the same job; in its greater emphasis on social analysis, and more detailed procedures for this, there is certainly something to contribute to land evaluation.

The papers on erosion hazard and conservation needs gave clear examples of assessment in physical terms. One feature which appeared in discussion was the lack of a clear method for prediction of the effects of erosion on crop yields, or other economic consequences. Work on this important subject is in progress.

On the theme of the application of land evaluation for conservation to support decisions in land-use planning, we were given a broad coverage of procedures in Bulgaria and a specific example from Tunisia. To cover this topic adequately, however, it would have been desirable to have more examples of practical planning, and its outcome in project implementation. We did not have with us enough people who had been land-use planners or managers of land development projects, to tell us what were their real requirements from land evaluation.

The major purpose of the meeting has been to bring together scientists from different countries, with varying backgrounds, to share ideas and experience. This has led to an increased mutual awareness of methods and problems, and maintained the momentum of the study of land evaluation. With over 50 participants, 20 papers, and ample opportunities for discussion, not to mention the informative field excursions to the ITC facilities and to the remarkable achievement in conservation at the Twickel Estate, this purpose has been amply achieved.

The way forward, in my view, is now to focus on the output end of land evaluation procedures: that at which the land-use alternatives and their consequences, as presented in the results of land evaluation, are placed in the hands of planning authorities for decisions and action. This will mean bringing together evaluation experts with land-use planners and project managers, to maintain contact with the practical development purposes to which land evaluation is directed.

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K.J. Beek

Rector ITC

Ladies and Gentlemen,
This is our last session. Since it was I who opened this workshop, I am also reponsible for closing it. At the beginning of the workshop I posed a number of questions, well aware of the saying that a fool may pose questions that may confound a thousand scientists.
Nevertheless, I feel that our meeting has furthered the cause of land evaluation, and I say this with a certain degree of satisfaction, because not so long ago (and I speak of 10-15 years) land classification – as it was called then – was not even considered to be a scientific matter. Once when I mentioned the subject I was told, 'Well, that is something for practioners, not for scientists'. During the past few years we have at least managed to complicate land evaluation so much that it may now convince even the strictest traditionalists that it must be a science after all!
I think that by now we have all understood that there is some logic in land evaluation. But there are still many important problems that have yet to be solved, and we have been trying to tackle some of them here.

Another important aspect of this meeting is that we have brought together a new combination of people: some old hands and some new blood. This meeting has opened doors – for all of us.
Working in different parts of the world, it is important that we not become too much bogged down by rigid procedures, that we stimulate people who can work together with understanding for each other's methods and techniques, and, above all, that we not lose sight of our common purpose. Most of us are specialists in the field of soils, land use, and vegetation. We are used to working in the field and have had personal experience with the land-use problems. To some it may seem that land evaluation is becoming such a broad issue that it may look like a religion. I found a telling printing error in an item I presented on the first day. It read: 'Adherence to specific mapping scales may avoid confession during the discussions...'. Well, I think we have had a pleasant mix of confessions and confusions, and the outcome has been most constructive.
a. In the first place, we have agreed that we have to consider all the available technology for land evaluation and land-use planning. We should make full use of the new tools on the market if these will facilitate our task – paying particular attention to the modelling and development of information system and the use of computers – wherever we are working.
b. Another very important matter for consideration at this meeting has been the farmer's central role in the use and conservation of the land, seeing the soil from the point of view of the user. That is why we have introduced the land utilization concept; the use must be relevant when we formulate land-use recommendations. We speak of land evaluation, but in fact we are discussing land-use evaluation, trying to make land-use suitability classifications. We look at the land-use system as a whole and then we evaluate its potential. Professor Cline, while teaching soil science at Cornell, always said: 'You must try to look at soils the same way the farmer does'. That is

easier said than done, and it requires very much training. Right from the start, students must be trained to get a 'feel for the field' to give them the right 'eye' for looking at soils. Land evaluation can help make the complex structure of what you are looking at more simple, enabling you to analyze one element of the system at a time and to integrate your findings later. Nowadays eye functions can be simulated by computers. An article in Scientific American on some kind of cycloptron, a digital eye that could see a lot of things without understanding what it saw, concluded that 'There can be no sight without insight'. We have been talking here about getting more insight, with particular reference to sloping areas. There is still a lot to be learnt by measuring and relating ongoing processes. Particularly on larger scales, land evaluation is not so much concerned with dividing the land into classes, as with relating outputs to inputs. In sloping areas, outputs are not only the yields; unfortunately the soil itself may leave the system, an unwanted output that we call 'environmental effect'. In dealing with the problem, one has to try to ensure that inputs, effects, and outputs reach some kind of acceptable level.

c. Not so long ago I was asked by the Dutch Government to go to Spain in connection with a Dutch programme of re-settling immigrants in their home countries. In this case we were dealing with guests workers who had been employed in Dutch steel mills and who were now going back to Spain. They had received a financial premium to farm there. I found excellent, first class, irrigable land in the south of Spain, But the repatriates decided on a slope of about 50% with a sprinkler installation and a strong erosion hazard. It was, however, near a town with good schools. The aspirations of the people involved should never be overlooked.

d. This has been an unusual meeting since we have concentrated on a specific land-use problem – land degradation in sloping areas – and not on a major kind of land use as we have done in previous meetings. Meetings like this can lay the groundwork for future decision-making policy, so the decision to attend may have far-reaching consequences. Over the last twenty years or so, we have come to know and respect many regular participants of these meetings on land evaluation – the methodology of which has become a recurrent theme in their scientific lives. We have seen Professor Bennema (*) at several sessions. Vink has retired, and did not join us this time.

But new people are joining, and some people (though not enough) from developing countries were able to attend. By holding this workshop at the ITC we hoped to see at least some of our students and alumni – professionals from developing countries.

The ISSS is an important organization primarily because it ensures some continuity in our scientific research. In Europe we have the advantage of representing a number of countries with very different languages and cultures, so that international cooperation becomes something of a necessity. When you come from a big country like Canada, Brazil, or the USA you can spend a lifetime doing research without looking over the border. I think the ISSS is one of the means of avoiding too much isolation, and through our working groups and international congresses we can orientate research within a time span of four to eight years. In 1986 there will be the World Congress of the Society of Soil Science in Hamburg, attended by our working group. In November 1985 there will be a world conference on soil conservation in Venezuela.

* Prof. Dr. Jacob Bennema died suddenly of a stroke. Tragically, his farewell lecture had to be circulated posthumously. This was the last land evaluation conference to which he contributed. During the meeting he emphasized the responsibility of soil scientists for soil conservation!

e. Our meetings on land evaluation have the continuous support of the FAO. It seems that the FAO can and does give such a high priority to land evaluation. The FAO is a very important promotor of better land use and conservation in the world – through the field projects and thanks to the staff at Headquarters, who make sure that guidelines and papers are written. Therefore, I am particularly grateful to Purnell and Sanders of the FAO for being here and assisting us in this meeting. I should also like to thank UNEP.

f. With regard to the recommendations, since this is a scientific meeting, I think that these are meant firstly for ourselves and our colleagues in the ISSS. There is little to be gained by approaching agencies without money and governments with other priorities. Recommendations are usually best followed up by the scientists themselves. They are of particular relevance to those dealing with soil conservation in sloping areas, especially where there is confusion and overlap between the different disciplines.

Our working group has always published its results through the International Institute for Land Reclamation and Improvement (ILRI), and ILRI will also print this report. ILRI has very good world coverage. This will help us in improving international communication, as done also through the FAO.

The word communication has been mentioned several times. Our meeting has contributed to better communication between disciplines, and perhaps even between our disciplines and the farmers with whom we work.

Before closing this workshop, I should like to thank several people for their contribution.

In the first place, of course, may I express my thanks to all of you for doing so much to make this meeting a success by bringing in your papers and taking an active part in the discussions. You have all been excellent participants. We have very much enjoyed having you here at the ITC. Some people have been responsible for the big jobs, I mention especially Purnell, Sanders, and Driessen, who prepared the keynote addresses for the first day. As a souvenir I should like to present them with a map of The Netherlands, prepared from our satellite images made at an altitude of 900 km.

Finally, I should like to thank the technical and secretarial staff, in particular Dr. Siderius, for their dedication in the preparation and organization of this meeting.

I wish you all a safe journey home, a Merry Christmas, and a Happy New Year. I look forward to seeing you again at future meetings. The first occasion will be a combined workshop with the Working Group 'Soil Information Systems' on the subject of 'Quantified Land Evaluation Procedures' in Washington, USA, from 28 April to 2 May 1986.

Appendix 1

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Appendix 2

Programme

Sunday, 16th December 1984
Registration of the participants

Monday, 17th December 1984
Opening of the workshop and keynote address
Session I Chairman: K.J. Beek Secretary: W. Siderius

09.00–09.30	Opening addresses Welcome by K.J. Beek Official opening by W.G. Sombroek
09.30–10.15	Theme A M.F. Purnell The application of the FAO framework for land evaluation and land-use planning and conservation in sloping areas; potentials and contrains.
11.00–11.45	P.M. Driessen Erosion hazard and conservation needs as a function of land characteristics and land qualities.
11.45–12.30	Theme C F. Sanders Land evaluation for conservation to support decisions in land-use planning.
13.00–14.00	Lunch
14.30–16.00	Schermerhorn Lecture E.G. Hallsworth Resources for the future: measuring and managing the ultimate limit to growth
16.00–17.30	Reception hosted by the ITC.

Tuesday, 18th December 1984
Presentation of papers on working group themes 1, 2 and 3.
Session II Chairman: D.E. McCormack Secretary: G.W.W. Elbersen

08.30–09.15	A.C. Millington Reconnaissance scale soil erosion mapping using geographic information systems in LDC's
09.15–10.00	E. Bergsma Characteristics of mapping units in the rain erosion hazard surveys
10.00–10.30	A. Young The potentials of agro-forestry for land use in sloping areas
10.30–11.00	Coffee

11.00–11.30	Laurens J.P., van Vliet Soil erosion loss monitoring and prediction under semi-arid agriculture in the Peace River Region of N.W. Canada
11.30–12.00	A. Weeda and G.K.K. Gachene Land erosion hazard and its place in the FAO-framework; a case study from Machakos district, Kenya.
12.00–12.30	R. Ponce-Hernandez Land inventory and traditional agro-technology information for the mapping of land management units in central Mexico
12.30–14.00	Lunch

Session III

Working group sessions to discuss working group themes 1, 2 and 3 in relation to the main themes A, B and C.

14.00–15.30	Discussion
15.30–16.00	Tea
16.00–17.30	Discussion
1. 'Inventory'	Chairman: M. Stocking Secretary: A.C. Millington
2. 'Monitoring'	Chairman: L.P. van Vliet Secretary: H. Huizing
3. 'LUS & Cover'	Chairman: A. Young Secretary: H. van Gils
20.00–21.30	Continuation of the discussion.

Wednesday, 19th December 1984.

Presentation of papers of working group themes 4 and 5.

Session IV Chairman: M.F. Purnel Secretary: H. Huizing

08.30–09.00	A. Meijerink Spatial model for estimating gross erosion and sediment yields in data scarce, large areas using R.S. and geobase operations
09.00–09.30	K. Flach Modelling of soil productivity and related land classification
09.30–10.00	D.E. McCormack A comperative evaluation of the use of soil potential ratings for land-use planning in the USA and a developing country.
10.00–10.30	M. Stocking
10.30–11.00	Coffee
11.00–13.00	Working group sessions to discuss working group themes 4 and 5 in relation to the main themes A, B and C
4. 'Modelling'	Chairman: K.W. Flach Secretary: P.M. Driessen
5. 'Land suitability'	Chairman: T. Mitchell Secretary: A.N. Singh
13.00–14.00	Lunch
14.00–17.00	Excursion 1, visit to the 'Twickel' estate, aspects of cultural conservation
20.00–21.30	Continuation of discussion

Thursday, 20th December 1984.
Themes:
6. Implementation of soil conservation measures based on land suitability assessment;
7. Social and economic aspects of land conservation, priority needs of (small) farmers.

08.30–09.00	A.S. Lazarov Some aspects on the methodology of project design for land use of mountain territories
09.00–09.30	V. da Costa Land suitability evaluation based on resistence to erosion and other land qualities in a part of Kilifi District, Kenya
09.30–10.00	W. Siderius Drip irrigation as a method for soil and water conservation in sloping areas; a case study from Malaga Province, Spain
10.00–10.30	D. van Mourik Land evaluation and programme planning in sloping areas in Northwest Tunesia
10.30–11.00	Coffee
11.00–11.30	P.D. Jungerius Human settlement and its effect on the natural environment in Bei Boufrah (Central Rif, Morocco)
11.30–12.30	Poster sessions by Elbersen and Millington
13.00–14.00	Lunch at the ITC restaurant
14.00–15.00	Discussion on working group themes 6 and 7 at the ITC
15.00–17.30	Excursion 2: Visit to ITC: 15.00–16.00: Department Land Resource Surveys and Rural Development (I.S. Zonneveld, E. Bergsma H.A. Luning) 16.15–17.30: Image Processing Laboratory (N.J. Mulder) 16.15–17.30: Geo information systems, interactive cartographic system (D. Boonstra, E. van der Zee, A.M.J. Meijerink, G.W.W. Elbersen)

Friday, 21st December 1984
Preparation of conclusions and recommendations.
Session VI Chairman: A. Young Secretary: W. Siderius

09.00–11.00	A. Young: summing up
11.00–11.00	Coffee
11.30–12.00	Presentation of conclusions and recommendations
12.00–12.30	Closing speeches: K.J. Beek K.W. Flach
13.00–14.00	Lunch
P.M.	Departure participants.

Currently available ILRI publications

No.	Publications	Author	ISBN No.
11	Reclamation of salt-affected soils in Iraq.	P. J. Dieleman (ed.)	–
14	Irrigation requirements for double cropping of lowland rice in Malaya.	G. A. W. van de Goor and G. Zijlstra	90 70260 840
15	Planning of service centres in rural areas of developing countries.	D. B. W. M. van Dusseldorp	–
16	Drainage principes and applications (in 4 volumes)	–	90 70260 123, –131, –62 X and –63 8
16^S	Principos y aplicationes del drenaje (en 4 volúmenes).	–	–
17	Land evaluation for rural purposes.	R. Brinkman and A. J. Smyth	90 70260 859
19	On irrigation efficiencies.	M. G. Bos and J. Nugteren	90 70260 875
20	Discharge measurements structures.	M. G. Bos	–
21	Optimum use of water resources.	N. A. de Ridder and A. Erez	–
22	A framework for land evaluation.	R. Brinkman and A. Young	–
23	Land evaluation for agricultural development.	K. J. Beek	–
24	Drainage and reclamation of salt-affected soils.	J. Martinez Beltrán	–
25	Proceedings of the International Drainage Workshop.	J. Wesseling (ed.)	90 70260 549
26	Framework for regional planning in developing countries.	J. M. van Staveren and D. B. W. M. van Dusseldorp	90 70260 832
27	Land reclamation and water management.		90 70260 689
29	Numerical modelling of groundwater basins: A user-oriented manual.	J. Boonstra and N. A. de Ridder	90 70260 697
30	Proceedings of the Symposium on Peat Lands Below Sea Level.	H. de Bakker and M. W. van den Berg	90 70260 700
31	Proceedings of the Bangkok Symposium on Acid Sulphate Soils.	H. Dost and N. Breeman (eds.)	90 70260 719
32	Monitoring and evaluation of agricultural change.	Josette Murphy and Leendert H. Sprey	90 70260 743
33	Introduction to farm surveys.	Josette Murphy and Leendert H. Sprey	90 70260 735
34	Evaluation permanente du développement agricole.	Josette Murphy and Leendert H. Sprey	90 70260 891
35	Introduction aux enquêtes agricoles en Afrique	Josette Murphy and Leendert H. Sprey	90 70260 956
36	Proceedings of the International Workshop on Land Evaluation for Extensive Grazing (LEEG).	W. Siderius (ed.)	90 70260 948
37	Proceedings of the ISSS Symposium on 'Water and solute movement in heavy clay soils'.	J. Bouma, P. A. C. Raats (ed.)	90 72060 972
38	Aforadores de caudal para canales abiertos.	M. G. Bos, J. A. Replogle and A. J. Clemmens	90 70260 921
39	Acid Sulphate Soils: A baseline for research and development.	D. Dent	90 70260 980
40	Land evaluation for land-use planning and conservation in sloping areas.	W. Siderius (ed.)	90 70260 999

No.	Bulletins		
1	The auger hole method.	W. F. van Beers	90 70260 816
4	On the calcium carbonate content of young marine sediments.	B. Verhoeven	–
6	Mud transport studies in coastal water from the Western Scheldt to the Danish frontier.	A. J. de Groot	–

No.	Bulletins	Author	ISBN No.
8	Some nomographs for the calculation of drain spacings.	W. F. J. van Beers	–
9	The Managil South-Western Extension: An extension to the Gezira Scheme.	D. J. Shaw	–
10	A viscous fluid model for demonstration of groundwater flow to parallel drains.	F. Homma	90 70260 824
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11F	Interprétation et discussion des pompages d'essai.	G. P. Kruseman and N. A. de Ridder	–
12	Gypsifereous Soils.	J. G. van Alphen and F. de los Rios Romero	–
13	Groundwater hydraulics of extensive aquifers.	J. H. Edelman	90 70260 794
No.	Bibliographies		
7	Agricultural extension in developing countries.	C. A. de Vries	–
8	Bibliography on cotton irrigation.	C. J. Brouwer and L. F. Abell	–
9	Annotated bibliography on surface irrigation methods.	S. Raadsma, G. Schrale	–
10	Soil Survey interpretation.	R. H. Brook	–
13	Abstract journals on irrigation, drainage and water resources engineering.	L. F. Abell	–
18	Drainage: An annotated guide to books and journals.	G. Naber	90 70260 93 X
	Other publications		
	Papers International Symposium Polders of the World (3 volumes).		90 70260 751 76 X and –778
	Final Report Symposium Polders of the World.	–	–