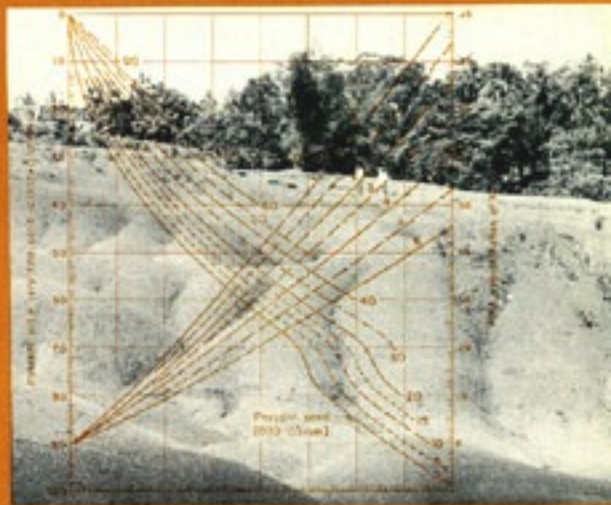


## assessing soil degradation



FOOD AND AGRICULTURE ORGANIZATION  
OF THE UNITED NATIONS ROME

## CONTENTS

	<u>Page</u>
I. INTRODUCTION	1
II. CONCLUSIONS AND RECOMMENDATIONS	2
III. BACKGROUND DOCUMENT - PART 1 AND 2	3
IV. TECHNICAL PAPERS AND DISCUSSIONS	
1. Studies of erosion and sedimentation in the IHD and the International Hydrological Programme of Unesco: F. Fournier	5
2. Water erosion assessments: G.R. Foster	6
3. Erosivity in tropical countries: R. Lal	7
4. Methodology used to determine the maximum potential average annual soil loss due to sheet and rill erosion in Morocco: H.M.J. Arnoldus	8
5. Application of Landsat imagery to the assessment of soil degradation: J. Riquier	9
6. Criteria for assessing wind erosion: E.L. Skidmore	10
7. Current and potential salinity of soils: I. Szabolcs	10
8. Criteria for assessing current and potential waterlogging - an introduction: F.I. Massoud	11
9. Influences of agricultural practices on soil degradation: R. Fauck	12
10. Cultural and conservation practices as factors for degradation assessment: C. Charreau	13
11. Land use and soil degradation: E. Roose	15
12. Role of inorganic fertilizers in the chemical degradation of Nigerian savanna soils: Uzo Mokwunye	16
V. COUNTRY REPORTS	
13. Assessment of land degradation in agricultural and pastoral areas in Australia: H.W. Pauli	17
14. Evaluation of soil erosion and degradation in the Arab countries: R.R. Gaddas	18
15. Soil degradation in the Republic of Argentina: J.C. Musto	19
16. Experience of data collection for assessment of soil degradation in East Africa: I.J. Kowal	20
17. Soil degradation assessment in Hungary: I. Szabolcs	20
18. Soil degradation in India: Y.P. Bali and J.S. Kanwar	20
19. Soil degradation in Senegal - actual situation and perspective: G. Beye	21
20. Notes on soil degradation, its assessment and reclamation at selected sites in Turkey, Spain and Kenya: T. de Meester	21
21. Soil degradation assessment in the USA: G.R. Foster	22
Discussion	22

	<u>Page</u>
VI. MAP LEGEND	23
ANNEX I. Agenda	24
II. List of participants	25
III. Background document	
Part 1 - World assessment of soil degradation - Phase I: H.M.J. Arnoldus and J. Riquier	29
Part 2 - Philosophy of the world assessment of soil degradation and items for discussion: J. Riquier	36
IV. Methodology used to determine the maximum potential average annual soil loss due to sheet and rill erosion in Morocco: H.M.J. Arnoldus	39
V. Soil degradation map of Morocco: J. Riquier	49
VI. Criteria for assessing wind erosion: E.L. Skidmore	52
VII. Assessment of land degradation in agricultural and pastoral areas in Australia: H.W. Pauli	63

## I. INTRODUCTION

On behalf of the Director-General of FAO, the Session was opened by Dr. R. Dudal, Director of the Land and Water Development Division and Dr. F. Mathez, Programme Officer of the Division of Ecosystems and Natural Resources of UNEP.

In his introduction, Dr. Dudal emphasized the urgent need for a better understanding of the risks of soil degradation and their geographical distribution as well as a better knowledge of where degradation occurs at present. This knowledge is absolutely vital for sound agricultural planning and agricultural adjustment. He pointed out that, among the constraints to soil conservation work, the lack of immediate returns is often a deterrent, since benefits from soil conservation are a long term proposition. It would be desirable therefore to combine soil conservation activities with other elements for increasing crop production. In terms of economic benefits it may not always be possible to prevent soil degradation totally, but it should in any case be reduced to permissible levels. Dr. Dudal then put the consultation in the perspective of the United Nations World Food Conference, which adopted a resolution <sup>1/</sup> to establish a World Soil Charter, recognizing the land resources of the world as a common inheritance, which need to be managed and preserved for the benefit of mankind.

Dr. Mathez stressed that in particular erosion, salinity and alkalinity and the loss of soil fertility seriously reduce the natural potential of soils to produce food and fibres. He indicated that the assessment of soil degradation should not be an aim in itself, but should be followed by action programmes in the field. UNEP's Global Environmental Monitoring System (GEMS) is expected to provide the necessary basis for the subsequent monitoring of soil degradation phenomena.

Messrs. Pérot and Higgins explained the relationships between the Global Assessment of Soil Degradation and other activities in FAO, such as the FAO/Unesco/ISSS Soil Map of the World (which serves as a basic document for the project), the UNEP/FAO/Unesco/WMO World Map of Desertification and the appraisal of present and potential land use by agro-ecological zones, which is a first approximation to a global land evaluation.

Mr. Riquier presented the background paper (Annex III part 1) and underlined the major items for discussions during the meeting (Annex III part 2).

After the introductory statements the meeting adopted the provisional agenda (Annex I) and agreed to devote some extra time to a discussion on the legend of the UNEP/FAO/Unesco/WMO world Map of Desertification owing to the presence in Rome of Dr. B. Rozanov, Senior Programme Officer of the Secretariat of the United Nations Conference on Desertification. The meeting approved the legend. <sup>2/</sup>

---

<sup>1/</sup> Resolution VI, World Food Conference, Rome, 1974.

<sup>2/</sup> The World Map of Desertification was printed in May 1977 as document A/CONF.74/2 and is available in Arabic, Chinese, English, French, Russian and Spanish from UNEP, Nairobi.

## II. CONCLUSIONS AND RECOMMENDATIONS

Although no formal recommendations were made by the meeting, as this was not intended in the first place, it was felt that certain points of emphasis had emerged from the discussions.

It was suggested several times that a pilot field project should be added to the main project in order to improve further the methodology because, although desk studies are valuable, they need confirmation through field testing. Moreover, it was stressed by various participants that if a computerized data processing system adapted to a specific country's needs is to be one of the results of the project, then field testing of the system is essential.

A second point was that the methodology proposed by the project staff was considered acceptable, although preferably the capability of the environment to provide protection by its vegetative cover against soil degradation should be taken into account. <sup>1/</sup>

During the meeting, many criteria to assess the various types of soil degradation were outlined by the experts. However no uniform methodology for quantitative assessment of soil degradation was presented by the participants except for the assessment of water and wind erosion. The methodology used in Australia for the assessment of actual soil degradation was well balanced, but cannot be extrapolated to other areas without substantial modifications.

The results of various national and regional assessments were presented by the participants. These can be used, after a correlation process, directly for the map showing actual soil degradation, and they also provide some guidelines for the map of potential degradation.

Finally, the principles of the proposed legend were agreed upon, but since no draft of the map of Africa north of the equator was yet available, the meeting decided to leave the details of the legend in the hands of the project staff.

---

<sup>1/</sup> A promising parameter has emerged from other studies as a criterion for this capability: it is the length of growing season. C.f. also the Australian system quoted in Annex VII. Furthermore, other annexes contain specific details concerning the methodology.

### III. BACKGROUND DOCUMENT

The background document 1/ reviews the history of the project from the United Nations Conference on the Human Environment held in Stockholm in 1972 to the present Expert Consultation.

The objectives of the project are to establish the facilities and methodology for a global assessment of soil degradation, and to initiate a global assessment of actual and potential soil degradation based on the compilation of existing data and the interpretation of environmental factors which influence the extent and intensity of soil degradation. This assessment will be started in Africa north of the equator and the Middle East as a test case, with the ultimate goal of drawing up a World Map of Soil Degradation.

In the section outlining the philosophy of the project, soil degradation is defined as:

"Soil degradation is a result of one or more processes which lessen the current and/or potential capability of soil to produce (quantitatively and/or qualitatively) goods or services".

Furthermore it is pointed out in this section that, although the establishment of a methodology for assessment and the actual soil degradation assessment are two different exercises, the methodology discussed should be restricted to those processes whose results are mapable at the envisaged scale (1:5 000 000), but refinements of the methodology should be possible for use at larger scales.

Classes of degradation intensity, as far as the assessment of current degradation is concerned, should be based on the intensity of the processes and not on their results, in order to eliminate the factor 'time', and because the results of soil degradation are a subject for land evaluation.

The evaluation of potential soil degradation or soil degradation hazards will indicate the maximum natural vulnerability to soil degradation, assuming that the soil is not protected against degradation forces.

The Director-General of FAO asked Member Governments to designate a focal point for their countries (institution or individual) to serve as a contact for collection and compilation of basic information on soil degradation. At the time of the preparation of this report, 54 governments have designated such a focal point. In addition to this, four consultants have visited a total of 30 selected countries to collect existing information on soil degradation and related subjects.

Studies undertaken so far concentrated on: 2/

- application of remote sensing techniques;
- collection and compilation of meteorological data that determine climatic aggressivity;
- general outline of a methodology and selection of uniform criteria to assess and monitor soil degradation, with emphasis at the present stage on soil erodibility with respect to water erosion.

---

1/ The background document is reproduced in full as Annex III, part 1.

2/ Technical papers on these studies will be presented in section IV of this report.

The following elements in the methodology are stressed in the background document:

- use and interpretation of existing maps;
- use of satellite imagery;
- use of existing prediction models;
- use of field data.

A tentative legend for the map is also proposed. In this legend, three intensity classes are distinguished: slight or nil, medium and high, while the other major criterion is the type of degradation process with two levels of detail, e.g.: moderate soil erosion by water: gully erosion, where moderate indicates the intensity, soil erosion by water indicates the process at the highest level, and gully erosion at the more detailed level.

Finally the background document draws attention to some specific problems:

- generalization of complex data;
- processes mapable at the 1:5 000 000 scale;
- selection of criteria for assessment;
- standardization of the criteria in some form to allow for automatic processing.

In the presentation of the background document emphasis was given to the problems encountered in the assessment of present and potential soil degradation. A supplement to the background document entitled "Philosophy of the World Assessment of Soil Degradation and Items for Discussion" <sup>1/</sup> prepared by J. Riquier was distributed to the participants. The difficulties that arise from changes in land use and management are particularly important for the assessment of potential degradation, and they were elaborated and illustrated with a graph.

#### Discussion

Mr. de Meester, commenting on the background document, made special reference to the proposed methodology for potential degradation assessment; in particular to the fact that, as said in an example concerning soil erosion by water, the protective effect of vegetation as well as that of management practices will be excluded. However, it was contended that the protective potential of the vegetation should be taken into account because, otherwise, it would be very difficult - if not impossible - to deduce the restrictions to the use of the land needed to reduce degradation.

The project staff answered that it was unrealistic to expect valid management directions from a map at a 1:5 000 000 scale, but agreed that the potential for recovery of vegetation was not uniform throughout the world. The distribution of effective rainfall over the year <sup>2/</sup> may be a satisfactory factor to express differences in the regenerative power of the vegetation, and some time will be devoted to a feasibility study of such factors.

---

<sup>1/</sup> This document is reproduced in full as Annex III, part 2.

<sup>2/</sup> Effective rainfall has been used in Australia as a factor for estimating water and wind erosion hazards. See paper presented by H.W. Pauli: "Assessment of Land Degradation in Agricultural and Pastoral Areas in Australia" (1975-76).

#### IV. TECHNICAL PAPERS AND DISCUSSIONS

##### Paper 1

##### STUDIES OF EROSION AND SEDIMENTATION IN THE INTERNATIONAL HYDROLOGICAL DECADE AND THE INTERNATIONAL HYDROLOGICAL PROGRAMME OF UNESCO

by F. Fournier

The International Hydrological Decade was launched in 1964. Sediment transport by riverflow was one of the subjects studied. The results served as the basis for the compilation of a World Map at a scale of 1:25 000 000 depicting suspended sediment loads of major rivers. The preliminary conclusions to be drawn from this map are that:

- in Africa and Latin America insufficient measurements have been taken upon which to base any conclusions on specific degradation in these areas;
- a relation exists between specific degradation and climatic aggressivity.

Besides climatic aggressivity, the location of the sampling point, i.e. distance to mountains or hills and to the sea, also has a marked influence on the sediment load measurements.

A new map is being prepared which will not only show sediment loads but also specific degradation and it will indicate clearly that differences in specific degradation between mountainous and non-mountainous areas are very pronounced. It would be very difficult to draw isolines on this map linking points with equal specific degradation, partly because of the scale and partly because of insufficient sample-density.

A study is currently being conducted on the relationships between annual rainfall, rainfall regime and sediment transports. Through analyses of graphs it has been established that five completely different relationships exist. The nature of these relationships has not yet been established precisely.

##### Discussion

From the discussion, it appeared that no analyses had been undertaken to link the findings of the International Hydrological Decade with climatic aggressivity since this was the subject of an earlier study by Fournier; <sup>1/</sup> this study found a definite relationship between specific degradation in large catchments and a climatic index.

The specific degradation is arrived at by ascribing the annual suspended sediment load measured to the catchment, so it does not equal gross erosion. No attempts have been made to correct the specific degradation by dividing it by a sediment delivery ratio in order to arrive at a gross erosion estimate.

---

<sup>1/</sup> Fournier, F.: Climat et érosion, Presses Universitaires de France, 1960.



by G.R. Foster

Two processes take place when soil is eroded: soil particles are detached and transported. Raindrop impact and flowing water are the detaching agents, run-off the transporting agent. Transported particles may be deposited or they may reach a water body, which can be the ocean. Thus the following negative effects result from soil erosion: degradation of arable land, transport of polluting chemicals absorbed by the eroded soil particles, pollution by the sediment itself.

Since the soil renews itself, although slowly, some erosion is permissible as long as no more soil is eroded than is formed. However, if the soil is removed faster, the quality of the soil as a crop growing medium decreases, production costs will rise and at a certain stage economic crop production will no longer be feasible.

In an assessment of water erosion the impact of pollution by sediment and chemicals should be taken into account, particularly because the rate of permissible erosion, as far as crop land is concerned, may have to be further reduced because of sediment damage.

Soil erosion assessments are a prerequisite for sound land use planning, in fact the actual and potential erosion assessment should be part of a land evaluation study of the area.

A model useful for the assessment of upland erosion is the Universal Soil Loss Equation (USLE) which may be expressed as:

$$A = RKLSCP$$

where: A = soil loss in mass/unit area

R = rainfall and run-off erosivity

K = soil erodibility factor

LS = topography factor for slope length and steepness

CP = cropping - management - supporting practices factor.

The equation is widely used in the USA to design conservation measures. Values for the various factors are readily available for the USA and are being developed for other parts of the world.

If values for the various factors of the USLE have not been worked out for a particular area, an expert with thorough knowledge of erosion principles can make reliable estimates. Often the values of the R-factor need to be adjusted to the area under consideration, since various rainfall characteristics may be different from those in the eastern USA. Extrapolation of the other factors is normally less troublesome. Although errors may occur this way, the results are generally more reliable than guesswork, because the interpreter is forced to consider the influence of all important factors if the USLE is used.

The form that erosion takes: sheet erosion (interrill erosion, rill erosion, gully erosion) is not automatically an indication of the degree of erosion.

The purpose of an erosion assessment is one factor to be considered when determining the methodology to be followed. If the purpose is to identify specific farm needs, the assessment must focus on the properties of the various farm fields; in a regional assessment a field by field assessment is not necessary, although one must keep in mind that the influence of extreme properties is greater than that of

average conditions. Consequently, a certain sampling technique will be appropriate. Any sampling must be based on statistical principles that will allow sound statistical analyses. Several sampling techniques using grids are mentioned, as well as the use of sample areas. If large areas need to be assessed, a breakdown in general land use classes, which are sampled separately, may be the appropriate way.

Ideally, all sample points should be visited in order to collect the relevant information, but this is not always possible. Other techniques, e.g. remote sensing, can yield acceptable approximations however, although some ground truth information is necessary as well.

Past erosion is a good indicator for erosion hazard, provided the land use does not change. In most cases however, land use alternatives should be taken into account. With the USLE this can be done.

### Paper 3

### EROSIVITY IN TROPICAL COUNTRIES

by R. Lal

In tropical countries improper management techniques may lead to serious erosion. This is due to the high aggressivity of tropical rains (high erosivity) more than to vulnerability of the soils, although large differences in vulnerability between various soil - landscape complexes exist.

Erosivity under tropical conditions is considered to be greater than in temperate regions. This is due to:

- larger median drop size in tropical rainstorms;
- higher rainfall intensities in tropical rainstorms; and thus consequently,
- higher kinetic energy of tropical rainstorms.

Since field experiments are time consuming, various scientists have developed empirical equations for the calculation of the rainfall erosivity index. In this paper several of these are reviewed and a new one, developed at IITA, Ibadan, Nigeria is introduced. This new index ( $AI_m$  - index) is reportedly applicable also in Australia, India and the Republic of Benin. It is calculated by multiplying the rainfall amount (cm) of a rainstorm by its maximum intensity (cm/hr). Numerically the differences between the  $AI_m$  - index and the R-factor of the Universal Soil Loss Equation are small so that the  $AI_m$  - index can be used as the rainfall factor in the Universal Soil Loss Equation.

METHODOLOGY USED TO DETERMINE  
THE MAXIMUM POTENTIAL AVERAGE ANNUAL SOIL LOSS  
DUE TO SHEET AND RILL EROSION IN MOROCCO <sup>1/</sup>

by H.M.J. Arnoldus

The maximum potential average annual soil loss due to sheet and rill erosion for Morocco has been evaluated using the Universal Soil Loss Equation (USLE). In order to arrive at the maximum potential soil loss, the value of the cropping management factor (C-factor) and the erosion control practice factor (P-factor) were chosen as unity (C = P = 1).

Since no adequate density of stations for which the R-factor has been calculated exist, an approximation was used. A study carried out at FAO indicates that a high correlation exists between the average annual rainfall and the index

$$\sum_{i=1}^{12} p_i^2/P,$$

in which  $p_i$  = average monthly rainfall and P = average annual rainfall. The results agree very well with the values of those stations for which the R-factor has been calculated in the traditional way.

Soil erodibility was determined using the soil erodibility nomograph developed for use with the USLE; in some cases an approximation was used if the percentage of very fine sand was unknown; slope factors were calculated from the FAO/Unesco Soil Map of the World.

The results are presented on four maps in Annex IV; one of them gives the maximum potential average annual soil loss as determined in this way and it ranges from 0-2 000 tons/ha/year; the map shows four classes: none to slight, moderate, high, very high.

#### Discussion

The papers of Foster, Lal and Arnoldus were discussed together. The first part of the discussion concentrated on the applicability of the USLE outside the USA. According to Foster there is certainly scope for use of the USLE in tropical countries also, if the interpreter is familiar with the area concerned and if he has good knowledge of erosion principles. If both conditions are met, intelligent judgement will result in assigning reasonable values to the various factors of the USLE. Also Foster pointed out that in view of the level of maximum accuracy possible on a 1:5 000 000 map, in some cases one can afford to make mistakes as high as 200% without serious errors being the result: e.g. a calculated soil loss of 12 tons/ha/year would be considered as the lowest class as well as a real soil loss of 4 tons/ha/year.

Concern was expressed that in the example of Morocco only the dominant soils of the Soil Map of the World were evaluated. Arnoldus explained that this study was presented as an example of methodology to be used, and that the methodology applies equally well to associated soils and inclusion of the mapping units. In this case, the map shows degradation hazard associations, which will be dealt with more fully when discussing the proposed legend.

---

<sup>1/</sup> This paper has been reproduced in full in Annex IV.

As far as the proposed procedure for calculating erosivity is concerned, it was pointed out that the precise relationship between the R-factor of the USLE and the

$$\sum_{i=1}^{12} p_i/P^2$$

index changes from one zone to another, therefore the relationships should be fitted to known values for some stations in a zone.

Paper 5

APPLICATION OF LANDSAT IMAGERY TO  
THE ASSESSMENT OF SOIL DEGRADATION

by J. Riquier

Conventional aerial photography shows many soil degradation features. Unfortunately, because of the vastness of the project area, conventional photography can only be used for pilot areas. Also, although many Landsat images are needed to cover the project area, it is nevertheless feasible to use them. However, some limitations are inherent in these images:

- the weak resolution (80-100 metres) does not permit the detection of many degradation features, e.g. gullies or other related factors like isolated strips of vegetation in desert zones, etc.;
- use of multispectral imagery is only useful if the signature of the various types of vegetation at different seasons is known and if several sets of images are available;
- there is insufficient ground truth readily available for automatic processing, use of density slicers, etc.;
- the workload, if an additive viewer is used, cannot be handled by the project.

A case study has been made of Morocco applying visual interpretation of black and white and false colour images (both at 1:1 000 000). From these images, a physiographic map was compiled. This map was then interpreted for soil degradation, using additional cartographic information (vegetation, topography, soil and land use maps). The map with the accompanying legend are reproduced in Annex V.

The main conclusions of the study are:

- physiographic regions which are more or less homogeneous as far as soil degradation is concerned, are easily distinguished on black and white images;
  - cultivated areas are not easy to distinguish if the field boundaries are irregular, but degraded vegetation can be recognized;
  - climatic zonation can be distinguished using false colour images, because humidity of the soils and vegetation is clearly expressed in the infrared;
  - salt flats are easily distinguished but saline soils can be confused with other high reflective soils, such as bare sand or alluvial fans;
  - degraded soils themselves cannot be distinguished and should be inferred from other criteria.
-

by E.L. Skidmore

Wind erosion is a serious problem in many parts of the world. Wind erosion physically removes from the field the most fertile portion of the soil and thereby lowers productivity, pollutes the air, reduces seedling survival and growth, fouls machinery, and imperils animal and human health. This paper presents criteria for assessing wind erosion on a regional basis by first assessing wind erosion on a field basis and then expanding to a region.

Solution of the wind erosion equation yields potential average annual soil loss from a given agricultural field. The equation is expressed as  $E = f(I, K, C, L, V)$ , where I is soil erodibility index; K is soil-ridge roughness factor; C is a climatic factor; and V is equivalent quantity of vegetative cover. Knowledge of soil properties, distribution and yield of major crops grown on each soil, local climate and dominant tillage and residue management practices of a region allow an estimate to be made of potential erosion from that region. Where such detailed information is unavailable, a less accurate but reasonable estimate of the wind erosion hazard can be obtained. The product of an appropriate climatic factor indicating the capacity of the wind to cause erosion and drying, the influence of local climate on surface soil, and the soil erodibility index indicate the intensity of the wind erosion hazards.

#### Discussion

A question was raised on the erodibility factor: does one take aggregates into account or only grain size? According to Skidmore both are important. The percentage of clods and grains is determined by sieving an air dried sample.

by I. Szabolcs

Salinity can be caused by acid, neutral or alkaline water soluble salts. The problem affects both soil and water. Salinity and alkalinity directly limit soil fertility.

The total area of current salt affected soils in the world is estimated at 952 062 000 ha. Their distribution depends inter alia on climatological and hydrological differences; salt affected soils and waters are common especially in semi-arid and arid zones. Some current salt affected soils can be used without reclamation measures, others however need radical reclamation.

A major part of the irrigated land risks becoming salt affected. More than half of the existing irrigation systems of the world have been damaged by salinity, alkalinity or waterlogging. Although the ISSS/Unesco/FAO Maps of Salt Affected Soils, in their present state, delineate those areas which are potentially saline or alkaline, it is difficult to estimate the total area. It can be stated, however, that this area is several times larger than the currently affected area. Potential salinity

---

1/ Contribution from the Agricultural Research Service, USDA, in cooperation with the Kansas Agricultural Experiment Station. Dept. of Agronomy Contribution No. 1647-a. This paper is reproduced in full in Annex VI.

can be estimated from:

- climatic factors such as: temperature, rainfall, humidity, vapour pressure, evaporation and their dynamics;
- geological, geomorphological, geochemical, hydrological, hydrogeological and hydrochemical factors;
- several soil properties;
- agrotechniques;
- irrigation practices.

Reliable prediction models can only be established if the following problems are solved:

- identification of main sources of water soluble salts;
- characterization of salt regime;
- determination of the effect of irrigation on water and salt regimes.

#### Discussion

It was stressed that the dynamics of salinity should be studied not only in a vertical profile, but also the lateral movements should be taken into consideration, always keeping in mind the vertical zoning of the soil profile: topsoil, salt accumulation (if any), unsaturated zone, saturated zone.

#### Paper 8

#### CRITERIA FOR ASSESSING CURRENT AND POTENTIAL WATERLOGGING - AN INTRODUCTION

by F.I. Massoud

The paper stresses the need for an accepted definition of waterlogging, since the term itself does not apply to what degree and during what duration the soil is wet. Also the water quality is very important. The author suggests the use of a watertable hydrograph or a similar concept to quantify the degree of waterlogging; the product of the height of the watertable (cm) above a critical level and the period of high watertable (days) is proposed as an index to express the degree of waterlogging. As an alternative, the integrated moisture content above the critical watertable depth in excess of that at field capacity over a given period of time, is given.

For the particular purpose of this project, a more practical definition is proposed: "waterlogging is the state whereby the soil becomes saturated with water within the depth of the active root zone for a period that affects yield and quality of economic crops". Degrees of plant tolerance to waterlogging could be:

- high = 0-20% yield reduction
- moderate = 20-40% yield reduction
- sensitive = more than 40% yield reduction

The following criteria to assess waterlogging are indicated in the paper:

- landform, particularly flat areas with limited internal drainage;
- hydrological conditions, particularly water balance, with special emphasis on inflowing water through seepage;
- soil conditions, particularly permeability, and other factors like high clay content, sodicity, low aggregate stability, stratification, organic matter content and clay mineralogy, etc.;
- soil classification, e.g. Gleysols and gleyic subgroups;
- climate, particularly intensity and distribution of rainfall, and potential evapotranspiration;
- management practices, since they can promote or prevent waterlogging;
- natural vegetation, particularly plant associations as they are very good indicators.

Paper 9      INFLUENCES OF AGRICULTURAL PRACTICES ON SOIL DEGRADATION

by R. Fauck

Three types of modification in soils can be distinguished:

- longterm modification over a long (geologic) period: pedogenesis;
- changes within the year, these are cyclic changes mainly affected by climatic factors (e.g. dry season - wet season); organic matter content, nitrogen content and pH are typical examples;
- fast changes within a time period of about a decade, not related to the annual cycle, bringing generally irreversible changes leading to a lower production potential of the soil.

Soil degradation processes belong to the third type of soil modification.

For the purpose of the consultation, agricultural practices are grouped as:

- mechanical practices: ploughing, tillage, clearing, etc.;
- practices to change the hydrological soil profile: irrigation, drainage;
- methods of exploitation: rotations, ley-farming, fallows;
- practices that add ions to the soil: fertilization, manuring, use of pesticides.

The first group influences especially the soil physical properties, after accelerating oxydation. This may change the erodibility of soils.

The second group of practices often has a profound influence on soil degradation, particularly on waterlogging, salinization and alkalinization.

The third group has a profound influence as well, especially on fertility, and through this on other degradation processes.

The last group influences the basic saturation particularly; results may be positive as well as negative as far as soil degradation is concerned.

The degree of influence of these practices depends on the intensity of application and on soil type: e.g. practices that pulverise the structure often increase the erodibility, although tropical soils with more than 20% kaolinite seem to be resistant to erosion independent of the practices used. Ploughing methods that do not turn the soil often reduce the soil erodibility. In loamy soils, these effects are more pronounced than in clay soils.

Effects caused by methods of exploitation are well documented, e.g. erosion hazards due to certain types of row cropping, the conservative effects of strip-cropping, and the negative effects of overgrazing. Therefore when planning agricultural practices, the following factors should be taken into account:

- erosivity;
- erodibility;
- waterbalance and its yearly evolution;
- pedogenesis (extrapolated in the future) i.e. the normal tendency to acidification, and depletion of organic matter;
- natural fertility, especially the nutrient reserves in the profile.

Irreversible degradation is not unavoidable. It is usually possible to find agricultural practices adapted to the soil and its environment which not only conserve but also improve. Today's technical knowledge is considerable, even in tropical countries.

Paper 10

CULTURAL AND CONSERVATION PRACTICES  
AS FACTORS FOR DEGRADATION ASSESSMENT

by C. Charreau

Major cultural practices are:

- soil tillage and seedbed preparation;
- management of harvest residues;
- density of planting;
- fertilization;
- weeding;
- control of pests and diseases;
- combination of crops
  - in time : rotations
  - in space: mixed cropping.



Ploughing serves a number of purposes:

- to improve soil physical properties in order to achieve a better rooting pattern;
- to eliminate harvest residues by incorporating them in the soil;
- to improve weed control;
- to prepare the seedbed.

In semi-arid West Africa it has been shown that deep soil tillage has many beneficial effects, particularly on the soils that have a sandy to coarse loamy surface texture. Furthermore, since tillage improves porosity and soil structure, in these soils a better rooting pattern and hence a better uptake of water and nutrients is achieved. Over 300 experiments in French speaking "Sahelian" countries in West Africa show that, in 90% of the cases, deep ploughing of the soil results in increased grain yields ranging from 10% to more than 100%. The advantages of ploughing at the end of the rainy season are i.a. conservation of moisture in the soil profile and good resistance to wind erosion (cf: emergency tillage). If organic matter is incorporated in the soil, the effects last longer.

Since tillage effects the water balance in the soil through improvement of:

- water infiltration in the soil;
- water uptake of plants;
- water conservation in the profile during the dry season;

it can be considered as one of the most effective ways to reduce the harmful effects of drought in the Sahelian countries.

The influence of ploughing on run-off and water erosion does not follow standard rules, because the total effect depends also on topography, soil-physical properties, the way ploughing is carried out, and the time elapsed between ploughing and the onset of the first heavy rains. In semi-arid tropical countries, on gentle slopes, erosion is sometimes reduced by ploughing because of:

- an increase in soil surface roughness, and thus a decrease of run-off velocity (Manning's  $n$ );
- a possible decrease in detachability of the soil;
- an increase in the protection provided by the vegetation (on cultivated lands) (reduction of Wischmeier's C-factor).

Therefore the statement that ploughing automatically increases soil erosion is false. In some cases it must be considered a conservation practice.

Theoretically the use of mulches as an erosion control tool is very interesting although little effect has been observed on soils ranging from sandy to clay loam. From the practical and economic point of view the use of mulches in the semi-arid tropical countries has little promise, because:

- much less vegetative matter is produced than in humid areas;
- straw and tops are used as cattle fodder or for domestic use (fuel);
- termite activity greatly increases if straw is present, thus causing a rapid breakdown.

The last part of the presentation was devoted to watershed conservation.

by E. Roose

The Ivory Coast has a big programme for the development of industrial plantations and mechanized agriculture. Soil degradation research is an important component of this programme.

Emphasize has been given to:

- conservation of soil fertility by using adequate cropping systems;
- evaluation of chemical and physical properties after clearing and mechanical cultivation;
- research on factors governing soil erosion, and on soil conservation methods;
- loss of fertilizers and colloids by surface and subsurface run-off and leaching.

ORSTOM and GERDAT have studied soil erosion in West Africa and Madagascar for over 20 years, using run-off plots. The following particular problems have been studied:

- fertilization;
- influence of soil cultivation on root systems and plant production;
- use of various kinds of grazed fallow;
- use of crop residues.

Some of the results show that:

- deep ploughing gives the best yield generally, but in some cases on ferralitic soils, zero or minimum tillage combined with mulching can be used economically, but weed and pest control become more difficult;
- considering grass fallow, the best physical and chemical effects are obtained after two years of fertilized graminæ or adapted legumes;
- although a rapid decrease is normal in physical and chemical properties of a soil after clearing, this trend can be stopped and often reversed by good management and a proper farming system;
- leaching of fertilizers is a problem mainly on ferralitic soils but not so much on ferruginous soils of the dry tropical area; the main elements lost are N, K, Mg and Ca;
- intensive use of acid fertilizers leads to rapid acidification of soils;
- water erosion hazards in the tropics are very great, particularly because of a high rainfall aggressivity; conservation measures should aim at establishing a good vegetative cover; terrace systems are not adapted to the economic, social and climatic conditions of the tropics;
- soil erodibility is not a stable property, but changes with time.

In conclusion, three questions were posed:

- 1) What detail can be mapped on a 1:5 000 000 map, particularly if one considers that in the field enormous differences can occur over only 50 m distance?
- 2) How can the hazard of leaching of fertilizers and soil structure destruction be indicated?
- 3) How can the dominant form of erosion (linear vs. non linear) be distinguished?

Paper 12

ROLE OF INORGANIC FERTILIZERS IN  
THE CHEMICAL DEGRADATION OF NIGERIAN SAVANNA SOILS

by Uzo Mokwunye

Savanna Soils are inherently low in natural fertility. Under traditional farming systems, the bush fallow period restores the natural fertility, but where continuous cropping is practised inorganic fertilizers are indispensable.

Chemical fertilizers however lead to a decline in soil pH and the subsequent loss of basic cations. In order to overcome this problem the following measures are suggested:

- recycling of mineral nutrients in the non-economic portions of the plant through appropriate residue management practices;
- formulation of new complete fertilizer recommendations.

Discussion

Opinions were divided on the use of mulches and zero tillage techniques vs. ploughing. Both opinions were supported by experimental data. However the desirability of maintaining organic levels in the soil was generally recognized.

In reply to the questions posed by Mr. Roose, it was stated that:

- a map at a scale of 1:5 000 000 can only be a very generalized map. At such a scale the smallest mappable area is represented by 0.25 cm<sup>2</sup> on the map or ca 625 km<sup>2</sup> in reality. Insufficient data exist to warrant a global assessment at a larger scale; therefore only those soil degradation processes that can be generalized at such a scale can be mapped.
- since some soils are more sensitive to leaching and soil structure deterioration, these hazards can be shown on the envisaged map.
- in areas where one form of erosion is clearly dominant over the others, they can be mapped as such; in many areas however, a distinction between linear and non-linear erosion cannot be made, and associations have to be mapped.

The importance of sound fertilizer recommendations was fully recognized. Some of the participants were of the opinion that special types of fertilizers need to be developed for acid tropical soils. The high phosphorus fixing capacity of some of these soils was pointed out as well. In some cases a high initial dose of phosphorus provides some solution.

## V. COUNTRY REPORTS

Paper 13

### ASSESSMENT OF LAND DEGRADATION IN AGRICULTURAL AND PASTORAL AREAS IN AUSTRALIA (1975-1976) 1/

by H.W. Pauli

Land degradation has been assessed in Australia. The results will be published in 14 reports in 1977.

In this study, land degradation was assessed in terms of treatment measures, since this way information is directly available on preventive and reclamation measures, and the results are directly quantifiable in terms of resource input, which consequently can be converted to a monetary basis.

The assessment was carried out separately for the arid and non-arid zones of Australia. In both zones it was carried out in the following four stage sequence:

- delineation and description of land zones and "types of country" and description of the land degradation within them;
- determination of treatment measures required to control the described degradation;
- quantification of the costs involved in the treatment measures;
- rating of the urgency of applying the treatment measures.

In addition, an attempt was made to assess the land degradation treatment requirements which could be expected to result from likely future land use changes caused by socio-economic forces. Therefore the influence of several environmental factors on degradation hazards was also evaluated.

#### Discussion

The coupling between land degradation and treatment measures was appreciated by many of the participants, who favoured such an approach also for the World Assessment, particularly since this facilitates land evaluation exercises. It was repeated that at a scale of 1:5 000 000 such a coupling, however desirable in itself, is not feasible and furthermore that the amount of data available for the Australian study is not representative for other large parts of the World. But if the global assessment is to be followed-up by national or regional inventories, an approach such as the Australian is certainly worthwhile.

The Australian delegate expressed his willingness to summarize the Australian study in conformity with the guidelines for the global assessment.

---

1/ This paper is reproduced in full in Annex VII.

EVALUATION OF SOIL EROSION  
AND DEGRADATION IN THE ARAB COUNTRIES

by R.R. Gaddas

The arid climate, common in most Arab countries, is conducive to soil erosion and other forms of degradation. Human and animal pressure led to the expansion of agriculture to marginal lands, while irrigation often caused secondary salinization. Animal husbandry has been ousted by increasing cultivation to small surfaces which suffer serious overgrazing and it extends into the forests as well.

Very few specific studies have been carried out, consequently soil degradation must be estimated from soil maps. Since mapping systems as well as soil conditions vary from country to country, it is difficult to make the necessary correlations at a regional scale.

The Arab Center for the Studies of Arid Zones and Dry Lands (ACSAD) has started to prepare a Map of Soils and Soil Productivity at a scale of 1:1 000 000. In this project, several soil correlators, assisted by a consultative group of which FAO is a member, will coordinate the regional studies. Remote sensing will be one of the tools used.

The Pasture Section of the Center carries out research in order to find palatable, drought resistant plant species that also have sand fixing properties and will withstand erosion. In addition the Center has several local projects in various Arab countries; for instance, there is a study on drainage improvement and desalinization in the Euphratus valley. Another example is in the Lattaquieh coastal strip on marl hills with an annual rainfall of about 900 mm, where water erosion is being studied. This type of erosion is particularly active in mountainous areas with steep slopes and on marl hills. Seriously affected areas can be found in the Rif Mountains of Morocco, Central and South Tunisia, the Ghariane and Jebel Akhdhar region in Libya; the coastal marl hills in Lebanon and Syria, the northern part of Iraq close to the Turkish border and the regions around the Nuba mountains, Ingessana and Jebel Marra in the Sudan.

Wind erosion is rife on sandy soils under pronounced arid conditions and is often triggered off by overgrazing and other forms of bad land use. It occurs all around the Sahara, even on lands with tree crops and many coastal areas suffer from this kind of degradation. Another area vulnerable to wind erosion is around watering points.

Salinization and rising of the watertable is another form of degradation of the arid zones. Salinization is accentuated when irrigation water is saline, soil texture fine and drainage poor. Detailed soil maps serve to locate salinization and areas susceptible to waterlogging. Serious salt and waterlogging problems are found in Mesopotamia, the Euphratus valley (especially in the gypsiferous crust areas), the Medjerdah valley and Kairouan plain as well as the southern part of Tunisia, the oases and the irrigated plains of Africa, the Nile valley and its Delta in Egypt, near Wad Medani in the Sudan (although not serious yet); the Arabian Peninsula, the Jordan Valley in Jordan, and on several alluvial plains in Somalia.

by J.C. Musto

Economically, agriculture is the most important enterprise in Argentina, thus conservation and ways to increase production are of permanent significance. In order to earn foreign exchange through export of agricultural products, new lands are continuously opened up for agriculture. Because of this expansion, areas of land at best marginally suitable for agriculture have been put under cultivation. Since management practices are not always adequate for the soils, serious soil degradation problems occur and the use of soils, of which the suitability is unknown, has also created soil degradation problems, from soil erosion to desertification.

Argentina can be divided into three major agro-ecological zones, based on differences in the moisture regime:

- humid zone
- semi-arid zone
- arid zone

In the humid zone, sufficient water is available to cover the needs of agriculture. This zone comprises ca 24% of the country and large parts of it are affected by water erosion and temporary waterlogging. In 1957, it was estimated that 18 300 000 ha or 13% of the total cultivated area in the country was affected by water erosion to which Luvic Phaeozems are particularly susceptible; severe yield reductions occur on these soils once they are eroded. Pellic Vertisols also suffer greatly from water erosion. Alluvial soils in the humid zone are badly affected by flooding and waterlogging, which halts production for prolonged periods. Also sedimentation may cause considerable damage.

The semi-arid region covers ca 15% of continental Argentina. Here wind erosion is a major constraint. Soils formed in aeolean deposits are particularly susceptible to wind erosion. In 1957, it was estimated that ca 16 000 000 ha were affected by such erosion. The areas affected are now being noticeably reduced through proper management and land use planning.

About 61% of the national territory or 171 000 000 ha fall in the arid zone. Grazing is the major agricultural activity, although along some of the rivers cultivated lands are found, often supported by irrigation.

Wind erosion and salinization are the dominant soil degradation processes in the arid zone and the former is often triggered by overgrazing and degradation of the vegetative cover. Although the crop production area is relatively small in the arid zone, economically it is very important because of the high-value crops that are cultivated. Excessive irrigation and inadequate drainage systems have caused the watertable to rise, resulting in salinization and alkalinization, especially in low lying areas.

Since the importance of soil degradation is appreciated in Argentina, many activities in the field of conservation as well as research into the causes of soil degradation are underway.

A map at a scale of 1:5 000 000 showing actual soil degradation in Argentina was added to the paper.

EXPERIENCE OF DATA COLLECTION  
FOR ASSESSMENT OF SOIL DEGRADATION IN EAST AFRICA

by I.J. Kowal

In order to collect data for the Global Assessment of Soil Degradation, four consultants were sent to Latin America, West Africa, East Africa and Near East Countries. They were to make personal contacts with national research institutions, government organizations and individual research and field workers, in order to collect existing information and to secure cooperation for further stages of the project. The reporting consultant visited Botswana, Zambia, Tanzania, Kenya, Somalia and Sudan. In all countries he found much interest in the project and a willingness to cooperate, also that a deep appreciation of the dangers of soil degradation exists among the technical people. In spite of this, there are hardly any records on rates of soil degradation, neither are significant parameters systematically monitored. The few existing reports are unconnected and mainly descriptive. Thus data on rainfall intensity, wind velocity and wind direction are either unavailable or entirely lacking in East Africa.

Paper 17

SOIL DEGRADATION ASSESSMENT IN HUNGARY

by I. Szabolcs

Hungary is a small densely populated country and in consequence 70% of the land must be used for agriculture; no virgin land remains.

Soil degradation assessment and monitoring are facilitated by the existence of large government farms with centralized decision-making.

Maps of soil erosion and soil salinity covering the whole country have been made and they are based on the genetical principles of soil science.

Paper 18

SOIL DEGRADATION IN INDIA

by Y.P. Bali  
J.S. Kanwar

Two reports were presented on India, one by Y.P. Bali and the other by J.S. Kanwar. The following abstract is based on both reports.

Out of the total 328 million ha of India, 90 million ha suffer from water erosion, 50 million ha from wind erosion, 7 million ha are affected by salinity and alkalinity and 20 million ha suffer from flooding, thus a total of 167 million ha (51%) suffer from soil degradation. Moreover another 20 million ha in the canal irrigated areas run the risk of becoming degraded.

Water erosion threatens existing irrigation work through siltation, thus reducing the effective lifetime of reservoirs. Estimations put the loss of plant nutrients at 5.37 million tons of NPK annually because of erosion.

Soil degradation assessment in India is mainly qualitative and only in a few cases are full quantitative data available. A large variety of assessment techniques is used, ranging from small plot measurements to remote sensing.

Since irrigation resources are severely threatened by siltation, ICRISAT developed a system of small-watershed management, in which run-off water is guided through well protected waterways and stored in small reservoirs, to be used for supplementary irrigation.

Wind erosion is caused by destruction of vegetative cover and overgrazing. Extensive tracts of land are threatened with burial by wind blown sand. Crop damage by the abrasive action of sand-loaded wind and burying is extensive. It has been estimated by some that the Rajasthan desert has been expanding at a rate of half-a-mile a year for the last 50 years, but this has not been proved yet.

The coastal areas of Kerala and Tamilnadu, Andhra Pradesh and Orissa are being affected by marine erosion. Along the Kerala coast, the sea is encroaching at a rate of 2-5 metres/year and this erosion is primarily due to improper land use, although geological changes play a part as well.

Salinization and alkalization are also caused by poor management, particularly of faulty irrigation systems.

Paper 19

SOIL DEGRADATION IN SENEGAL -  
ACTUAL SITUATION AND PERSPECTIVE

by G. Beye

This paper describes the physical environment of Senegal, i.e. climate and soils, and the particular forms of soil degradation occurring in this country: wind erosion, water erosion, salinization, waterlogging and chemical and physical soil degradation.

According to this review, there is reason to be pessimistic since all forms of soil degradation occur in Senegal and unless conservation measures are urgently introduced, soil degradation will have a catastrophic impact on the national agricultural capability. Degradation phenomena occur in all parts of the country, the dominant process changing from zone to zone. A synthetic map was added to the paper. Optimistically though, agriculture can be intensified, leading to higher production while at the same time conserving the capital soil, if well-balanced farming systems, that take the whole of production techniques as well as conservation techniques into account, are introduced.

Paper 20

NOTES ON SOIL DEGRADATION, ITS ASSESSMENT  
AND RECLAMATION AT SELECTED SITES IN TURKEY, SPAIN AND KENYA

by T. de Meester

Specific forms of soil degradation, its assessment and possibilities for its reclamation are described for three selected project areas:

- arid, central Turkey (with Calcic Xerosols);
- Mediterranean southern Spain (two areas with Chromic Luvisols and Chromic Vertisols);
- humid tropical south-west Kenya (with Humic and Dystric Nitosols).



Soil salinization and sodication (alkalinization) and soil structure degradation are discussed for an extensively cultivated plain (Turkey). Soil erosion, compaction and surface sealing are discussed for undulating and hilly cultivated areas in different physical and socio-economic environments (Spain and Kenya).

Emphasis is on assessment by both field and laboratory studies, which concentrate on the estimation of aggregate stability as a major index for soil erodibility. Results are qualitative, unless backed by long-term measurements on rainfall, run-off and soil loss.

Recommendations for reclamation and conservation are often technically feasible, but possibilities and effectiveness of obvious measures such as a change in land use and management practices and/or the construction of terraces may be limited by land tenure, farm economics and social factors.

Paper 21

SOIL DEGRADATION ASSESSMENT IN THE USA

by G.R. Foster

Many agencies in the USA are concerned with natural resources survey. The Soil Conservation Service is the most important one as far as soils are concerned. Soil degradation assessments have been carried out in the past and the last updating took place in 1975. Several researchers work on quantitative evaluation of soil degradation hazards, often expressed in monetary terms (crop damage).

A land use survey has started that will be published on 1:250 000 scale sheets.

Discussion

There was general discussion on the papers presented in this section.

R. Tomlinson of Canada reported that a soil degradation inventory has been completed in Canada.

O. Azevedo of Portugal called attention to the infringement of urban agglomerations on agricultural lands. He plead for the establishment of a working group on soil conservation for the Mediterranean countries.

V. Egorov and N. Minashina of the USSR briefly introduced the genetic soil degradation classification system in use in the USSR and illustrated it with an example of salinity classification.

## VI. MAP LEGEND

A Soil Degradation Map legend was proposed in the Background Document (see Annex III). Messrs. Riquier, Pérot and Arnoldus explained how the proposed legend would tie in with the legend of the Soil Map of the World: e.g. Soil Map of the World Mapping unit Lc37 is composed of

- Dominant soil:       Chromic Luvisol (Lc)
- Associated soil:     Calcic Kastanozem (Kk)
- First inclusion:    Gleyic Luvisol (Lg)
- Second inclusion:   Calcaric Regosol (Rc)

Lc represents the dominant soil of the association and number 37 refers to the composition of the association.

After analysing the degradation processes occurring on all soils in the association at a specific recurrence of that mapping unit, the following (hypothetical) result is obtained:

- Lc: moderate sheet erosion:                En, medium
- Kk: slight wind erosion (deflation):        Wv, slight or nil
- Lp: slight excess of water, waterlogging:  Lg, slight or nil
- Rc: strong wind erosion (deposition):       Wd, high

Since En is the process occurring on the dominant soil, the soil degradation association will be called En. As for the soil associations, a number refers to the composition of the association of degradation processes. The list with all degradation associations with En dominant is checked and it is found that all 26 En associations have a different composition to that just found. Consequently this particular composition is called En27. En27 is the symbol occurring on the final map. The text accompanying the map contains a table on which can be found:

Mapping Unit	Dominant process	Associated process affecting 20% of the mapping unit	Included processes affecting 5-20% of the mapping unit
En27	En	Wv	LpRc

The colour of the unit on the map (orange) will indicate that the dominant process (En) has a medium intensity. Comparison with the soil map tells that soil map unit Lc37 has the composition indicated above (Lc; Kk; Lp; Rc), thus for each of the soils in the association the degradation process can be matched, but the intensity, given as a colour symbol, applies only to the dominant process, i.e. the process on the dominant soil.

### Discussion

The participants agreed with the proposed legend but felt that no final judgement could be made until it had been tried out more extensively.

AGENDA

Tuesday 18 January 1977

- Opening of the Expert Consultation
- Adoption of the Agenda
- Background of the World Assessment of Soil Degradation
- Assessment of Water Erosion
- Application of Landsat Imagery to the Assessment of Soil Degradation

Wednesday 19 January 1977

- Criteria to Assess Wind Erosion
- Current and Potential Salinity of Soils
- Criteria to Assess Current and Potential Waterlogging
- Influence of Land Use on Soil Degradation

Thursday 20 January 1977

- Country Reports
- Legend for a Soil Degradation Map

LIST OF PARTICIPANTS

Argentina

J.C. MUSTO  
Coordinador del Programa de Conservación y Fertilidad  
de Suelos  
Instituto Nacional de Tecnología Agropecuaria  
Centro Nacional de Investigaciones Agropecuarias  
Castelar

Australia

H.W. PAULI  
Director of Soil Conservation  
Queensland Department of Primary Industries  
William Street  
Brisbane 4000

Belgium

M. DE BOODT  
Faculty of Agriculture R.U.G.  
533 Coupure Links  
B 9000 Gent

Canada

R.F. TOMLINSON  
IGU Commission on Geographic Data Sensing and Processing  
17 Kippewa Drive  
Ottawa, Ontario K1S 3G3

France

R. FAUCK  
Office de la recherche scientifique et technique  
d'outre-mer (ORSTOM)  
24 rue Bayard  
75008 Paris

E.J. ROOSE  
Office de la recherche scientifique et technique  
d'outre-mer (ORSTOM)  
B.P. 20  
Abidjan  
Ivory Coast

Hungary

I. SZABOLCS  
Director of the Research Institute of Soil Science and  
Agricultural Chemistry of the Hungarian Academy of Sciences  
Herman Ottó ut. 15  
Budapest II

India  
Y.P. BALI  
Joint Commissioner (Soil Conservation)  
Ministry of Agriculture and Irrigation  
Department of Agriculture  
New Delhi

J.S. KANWAR  
ICRISAT  
1-11-256 Begumpet  
Hyderabad-500016, A.P.

Netherlands  
T. DE MEESTER  
Lecturer, Department of Soil Science and Geology  
Agricultural University  
Duivendaal 10  
P.O. Box 37  
Wageningen

Nigeria  
R. LAL  
Soil Physicist  
International Institute of Tropical Agriculture (IITA)  
Oyo Road  
P.M.B. 5320  
Ibadan

Uzo MOKWUNYE  
Soil Science Section  
Ahmadu Bello University  
P.M.B. 1044  
Zaria

Senegal  
Gora BEYE  
Director  
Centre national de l'Institut de recherche agronomique  
Bambay

C. CHARREAU  
ICRISAT  
B.P. 3340  
Dakar

Syrian Arab Republic  
R. GADDAS  
Arab Center for the Studies of Arid Zones and Dry  
Lands (ACSAD)  
P.O. Box 2440  
Damascus

United States of  
America  
G.R. FOSTER  
Hydraulic Engineer  
USDA, Agricultural Research Service  
Agricultural Engineering Building  
Purdue University  
West Lafayette, Indiana 47907

E.L. SKIDMORE  
Soil Scientist  
USDA, Agricultural Research Service  
Agronomy Department, Waters Hall  
Kansas State University  
Manhattan, Kansas 66506

U.S.S.R.

Nina MINASHINA  
Chief of the Laboratory of Genesis and  
Improvement of Irrigated Soils  
\*Dockuchaev's Soil Institute  
Moscow

Valentin EGOROV  
Director of Dockuchaev's Soil Institute  
Moscow

Unesco Representative

F. FOURNIER  
Unesco  
7 Place Fontenoy  
75700 Paris

UNEP Representative

F. MATHEZ  
Programme Officer  
UNEP  
P.O. Box 30552  
Nairobi  
Kenya

Observers

B. ROZANOV  
Senior Programme Officer  
Secretariat of the United Nations Conference  
on Desertification  
P.O. Box 30552  
Nairobi, Kenya

O. AZEVEDO  
Centro de Investigação Mesológica  
Tapada das Necessidades  
Lisboa, Portugal

Józef TOBJASZ  
Via Ceruso 5, Int. 9  
Rome, Italy

FAO

R. DUDAL  
Director  
Land and Water Development Division (AGL)

F.W. HAUCK  
Chief  
Soil Resources Development and Conservation Service (AGLS)

A. PECROT  
Senior Officer (Soil Resources), AGLS

P. DIELEMAN  
Senior Officer (Drainage and Reclamation), AGLW

J. RIQUIER  
Project Coordinator, AGLS

H.M.J. ARNOLDUS  
Technical Officer (Soil Conservation), AGLS

FAO (continued)

G.M. HIGGINS

Project Coordinator, Agro-Ecological Zone Study, AGLS

J. KOWAL

Consultant, Agro-Ecological Zone Study, AGLS

F.I. MASSOUD

Technical Officer (Land Reclamation and Development), AGLS

F.L. SCHILLER

Secretary, AGLS

H. TONKIN

Editorial and Meetings Assistant, AGL

BACKGROUND DOCUMENT  
FOR THE  
FAO/UNEP EXPERT CONSULTATION ON THE PROJECT:  
WORLD ASSESSMENT OF SOIL DEGRADATION - PHASE I

1. INTRODUCTION

As an immediate result of the United Nations Conference on the Human Environment held in Stockholm in 1972, FAO and UNEP held an Expert Consultation on Soil Degradation, in Rome from 10-14 July 1974. <sup>1/</sup> This Expert Consultation adopted the following recommendations:

1. Recognizing land as an essential and limited resource and considering the adverse effect of different forms of soil degradation on future food supplies of the world, the Panel recommended that the Secretary General of UNEP and the Director-General of FAO be requested to give highest priority to soil conservation measures which are urgently required to ensure the supply of an adequate diet for increasing populations.

More specifically, on the basis of its technical deliberations, the Panel recommended:

2. That a global assessment be made of actual and potential soil degradation in collaboration with Unesco, WMO and ISSS. This assessment should be based on the compilation of existing data and on the interpretation of environmental factors influencing the extent and intensity of soil degradation such as climate, vegetation, soil characteristics, soil management, topography and type of land utilization: the results of this assessment should be compiled as a World Map of Soil Degradation.
3. That research be conducted on a methodology and criteria to measure and monitor soil degradation so that the data obtained are comparable for different areas and can be used to make predictions and extrapolations in areas where direct measurements cannot be made.
4. That a uniform procedure be set up for analysing, reporting and interpreting data with a view to providing a uniform system of description and classification of actual and potential soil degradation.
5. That guidelines be prepared for comprehensive data collection, processing and retrieval in a form usable for mathematical simulation modelling, computer mapping and computer data handling.
6. That investigations be promoted on aerial photograph interpretation and the application of other remote sensing techniques for the purpose of identifying, delineating and monitoring soil degradation and soil degradation hazards.

---

<sup>1/</sup> For a report of this meeting see "A World Assessment of Soil Degradation", an international programme of soil conservation, FAO MR/F3951.



7. That active cooperation be promoted between meteorologists, hydrologists and soil scientists for developing and refining meteorological data, such as water balance, rainfall intensity, wind velocity, air and soil temperatures, which are important factors in the determination of soil degradation hazards in different ecological zones.
8. That land evaluation activities be undertaken as a basis for soil conservation measures, so that degradation hazards can be avoided in the early stage of development by the selection of the most appropriate forms of land use.

It was also recommended to UNEP and FAO that an action programme be started.

As a result of these recommendations FAO, UNEP and Unesco started a project: World Assessment of Soil Degradation - Phase I, with the following objectives:

- i. to initiate a global assessment of actual and potential soil degradation based on the compilation of existing data and the interpretation of environmental factors which influence the extent and intensity of soil degradation;
- ii. to develop a methodology and select uniform criteria to measure and monitor soil degradation;
- iii. to prepare guidelines for comprehensive data collection, processing and retrieval in a form usable for mathematical simulation modelling and computer handling;
- iv. to promote investigations on the utilization of remote sensing techniques for the purpose of identifying, mapping and monitoring actual and potential soil degradation;
- v. to initiate studies for developing and refining meteorological data which determine climatic aggressivity and soil degradation hazards in different ecological zones.

Some guidelines were given in the project document for reaching these objectives:

"A first approximation of the identification of areas of potential degradation hazard for soil erosion by wind and water and for salinity-alkalinity will be made starting with one area (Africa north of the Equator and the Middle East) as a test case.

"This identification, which will be presented as a map of soil degradation at 1:5 000 000 scale, is to be performed by FAO jointly with Unesco, and with the cooperation of WMO and the ISSS, by using information existing in the archives of the FAO/Unesco Soil Map of the World and by incorporating the ISSS/Unesco World Map of Salt Affected Soils. In view of the volume of data to be handled, it is considered a necessity to develop a computerized system of data filing, processing, digitizing and retrieval based on the mapping units of the FAO/Unesco Soil Map of the World and compatible with the experimental computer programme for digitizing the Soil Map of the World.

"Meteorological criteria are considered essential in any assessment of potential hazards of soil degradation and have been used by some nations as a means of assessing the intensity of some forms of actual degradation. Consequently, studies are to be initiated to develop and refine local and regional meteorological information for application in evaluating soil degradation. These activities are to be conducted by interagency cooperation between FAO and WMO with the assistance of expert consultants and in collaboration with cooperating national governments.

"In view of the development of new technologies in remote sensing, studies are to be initiated at FAO to determine the applicability of various remote sensing techniques, especially satellite imagery, for identification and monitoring of one or more forms of actual soil degradation and/or areas of potential soil degradation hazard, or to determine the possibility of utilizing these techniques for identifying criteria that can assist in the delineation of affected or potentially affected soil degradation areas.

"Field truth studies are to be made in collaboration with current field projects and cooperating governments. A close cooperation will be maintained with the Global Environmental Monitoring System (GEMS) for the selection of areas, the types of soil degradation to be monitored and the criteria for monitoring soil degradation.

"The above activities will require the assistance of high level consultants and the organization of ad hoc expert consultations on specific problems."

## 2. PHILOSOPHY OF THE PROJECT

Discussions within FAO and with visiting scientists led to a philosophical background of the Project that can be roughly summarized as follows:

Soil degradation is a result of one or more processes which lessen the current and/or potential capability of soil to produce (quantitatively and/or qualitatively) goods or services.

Although the establishment of an assessment methodology and the mapping of soil degradation are two separate undertakings, the assessment methodology should be restricted to those processes whose results are mappable at the envisaged scale (1:5 000 000).

The methodology established should lend itself to refinements enabling mapping at larger scales.

The classes used in the current degradation assessment should be based firstly on the intensity of the active processes and not on the results of those processes on the decrease of soil productivity. The results of degradation processes are one of the criteria which are considered in land suitability evaluation and more particularly in the project on "Present and Potential Land Use by Agro-Ecological Zones". This project is another main activity in progress in the Land and Water Development Division, and is closely coordinated with the "Soil Degradation" Project.

The potential soil degradation evaluation will indicate the maximum natural vulnerability to soil degradation, assuming that the soil is not protected against the degradation processes, e.g. in the case of soil erosion, it is assumed that there is no vegetation and no protective management practices.

## 3. MAIN AREAS OF CURRENT ACTIVITIES OF THE PROJECT

The project started in November 1975 when a Project Coordinator was appointed. In January 1976, a Technical Officer, Soil Conservation, was added to the staff. The main activities and results obtained until now are the following:

1. A verbal note was sent by the Director-General of FAO to the member governments requesting them to designate a focal point (institution or individual) which would be our contact for collection and compilation of basic information on soil degradation in the respective countries. Until now we have received many replies showing government interest in this project. More specifically it is hoped that the correspondents will provide the project with the necessary data and will assist in the elaboration of the map, according to a uniform legend, in the improvement of the successive drafts and with getting approval of the final Soil Degradation Map in their respective countries.

1. Four FAO consultants are now visiting a number of selected countries to collect the existing information, meteorological data, maps of vegetation, geomorphology, geology and particularly maps of erosion already published. Such information has already been received from a number of countries and is being compiled.

2. Keeping in mind that finalization of the methodology for the assessment of actual and potential soil degradation is the objective of this meeting, the project activities in FAO Headquarters have concentrated on three main aspects:

- a. Investigations on the utilization of remote sensing techniques. A systematic study of Landsat imagery has been started on North Africa. A complete set of Landsat I imagery for Africa north of the Equator at 1:1 000 000 on four spectral bands is available in FAO. An almost complete set at 1:1 000 000 scale in false colours (Landsat II) on West Africa is also available.

A first attempt at using them was made on Morocco. The preliminary conclusions are that present soil degradation cannot be seen directly on this imagery but information on some main criteria which allow the assessment of soil degradation can be drawn from the images and particularly from Landsat II. The principal use of these images is to delineate accurately a physiographic unit or land system which is sufficiently homogeneous with regard to relief, climate, vegetation, soil and land use. The assessment of degradation will be based practically on non-numerical criteria grouped per classes: classes of slopes, type of soil, types of vegetation, etc. The classification of these criteria needs to be standardized at world scale.

- b. Collection and compilation of meteorological data which determine climatic aggressivity.

It was clear that the R factor in Wischmeier's equation is not calculable for most of the countries because of the lack of data, and not easily calculable even when data are available. It was decided to use the modified Fournier's index. The new index is

$$\sum_{i=1}^{12} \frac{pi^2}{P}$$

where pi is the monthly precipitation. The index shows a very good correlation with the R values calculated according to Wischmeier, but the equations of regression obtained are different by broad climatic areas.

- c. General outline of a methodology and selection of uniform criteria to assess and monitor soil degradation.

The work done was concentrated on soil erodibility by water. It was assumed that the use of the soil erodibility nomograph (Wischmeier et al., 1971) will give results with an acceptable accuracy. Erickson (1973) gives a nomograph that enables the estimation of the percentage of very fine sand. This nomograph has been added as a subroutine to the computerized soil erodibility nomographs of Wischmeier, and a large number of soils for which the erodibility could be calculated have been tested by this computer programme. The differences in "real" erodibility and approximate erodibility turned out to be acceptable. However, it appears that for many soils, of which descriptions are available in FAO, the pertinent surface textural classes are not given and often the soils for which the erodibility can be calculated cannot be considered a representative sample.

4. PROPOSED METHODOLOGY FOR THE COMPILATION OF THE DEGRADATION SOIL MAP AT  
1:5 000 000 SCALE

The methodology should be simple and make use of the existing methods of soil degradation assessment as applicable. It should also incorporate most of the data available. Other methods may have to be developed as required for assessing soil degradation in broad ecological areas.

Principal methods

1. Direct use of the existing maps: map of erosion, topographic map, map of salt affected soils. The International Society of Soil Science recently decided that the ISSS Map on Salt Affected Soils would be incorporated into the soil degradation map to be compiled by the FAO/UNEP project.
2. Interpretation of existing climate, geology, geomorphology, soil, topography, vegetation, land use maps, etc. Such interpretation and compilation of existing data will rely a great deal on the interpreter's judgement and his practical experience with specific environments. Basic knowledge of the different factors of soil degradation and their interactions is also necessary. A rating of such factors according to their respective "weight" in determining the intensity of soil degradation may have to be considered.
3. Utilization of satellite imagery (see above).
4. Utilization of existing models to calculate the erosion in watersheds. Unfortunately the data are often lacking for calculating the coefficients of the equation or the coefficients are established for particular watersheds and are based on measurable data. They are therefore not easily extrapolated to other watersheds. Also, the assessment by watershed is often difficult or impossible to generalize to one geomorphological area.
5. Field surveys of actual degradation. Quantitative data are supplied by a number of measurements of river sediment load and erosion on experimental plots. Field checks and rapid reconnaissance surveys could be carried out in certain areas by FAO field experts and country correspondents to the project to provide missing data. Such individual assessments may, however, be somewhat subjective with regard to the intensity of soil degradation and the extent of areas affected and should be complemented, whenever possible, by interpretation of aerial photos.
6. The possibilities of graphical representation of phenomena on a map at 1:5 000 000 scale should also be taken into account. The legend below is proposed for discussion by the meeting:

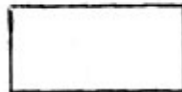
Legend of the map at 1:5 000 000 scale

Processes of degradation

E	erosion by water	n	sheet and rill erosion
		r	gully erosion
		m	movements of mass landslides
W	erosion by wind	v	dominant deflation
		d	dominant accumulation
L	excess of water	g	shallow groundwater
		f	recurrent flood
S	excess of salt	s	salinization
		a	alkalinization
P	loss of chemical fertility	o	loss of organic matter and humus
		p	loss of nutritive elements and acidification
		t	toxicity
D	physical degradation	b	sealing of surface, compacity in depth
		c	induration of certain horizons in depth

Intensity of dominant actual process

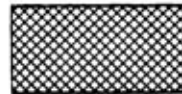
1. slight or nil



2. medium



3. high



## Symbolization of each cartographical unit

Eg. Er12

Er : process of degradation as above (Er = water erosion with formation of gullies; gully erosion)

12 : numbers which refer to the descriptive legend at the back of the map

$$Er12 = Er_3 + Po_2 + Lf_3$$

Er<sub>3</sub> : water erosion in gullies with high intensity (3); dominant in the mapping unit; is often the process affecting the dominant soil of the soil association

Po<sub>2</sub> : loss of organic matter of associated soils therefore processes affecting at least 20% of the mapping unit with a medium intensity (2)

Lf<sub>3</sub> : frequently flooded zone (intensity 3) but affecting only 5 to 20% of the mapping unit and often limited to inclusions in the soil association such as Fluvisols

## 5. ITEMS FOR DISCUSSION

The actual degradation can be mapped directly in the field, but it should also be estimated from specific criteria to fill up the gaps in the field surveys. Assessment of the potential degradation can be based on the same criteria.

In the selection of criteria, data which are representative of large areas should be selected, keeping in mind that such criteria will be used for the compilation of a map at 1:5 000 000 scale. Local or site data have limited interest unless they can be safely extrapolated to the area of a mapping unit. For instance, in the Wischmeier formula percentage and length of slope are used to calculate sheet erosion. In a mapping unit having a hilly or dissected topography where the slope characteristics vary greatly over a short distance, site data on slope would have little meaning. In such cases, and for mapping purposes, it is suggested that slope characteristics be replaced by geomorphological or landscape classes which will be defined in terms of average slope and altitude.

After selecting the criteria, a far greater difficulty is their combination according to the respective intensity and often their interaction, in order to assess the type and intensity of the processes of degradation. For the erosivity, a rating of each criterion has been selected and a multiplication of ratings. A first attempt was made with this method to assess the potential erosivity of Morocco.

Suggestions are invited concerning:

1. a list of processes of degradation which could be mapped at the scale of 1:5 000 000;
2. a selection of criteria for the assessment of the various forms of degradation and particularly erosion by water and wind;
3. a method for combining these criteria either mathematically, or with the help of tables allowing an automatic assessment of the degradation using standardized criteria available at regional scale.

PHILOSOPHY OF THE WORLD ASSESSMENT OF SOIL DEGRADATION  
AND ITEMS FOR DISCUSSION

by J. Riquier

1. DEFINITION OF SOIL DEGRADATION ADOPTED IN THE BACKGROUND DOCUMENT

As discussion continues on the definitions of the various kinds of soil degradation: geological, accelerated, normal, actual and potential, it may be opportune to specify at the outset of this meeting, which one was adopted for the project:

Soil degradation is a result of one or more processes which lessen the current and/or potential capability of soil to produce (quantitatively and/or qualitatively) goods or services.

Since soil degradation processes are continuous, a way of representing them is shown in the graph in Figure 1 which depicts soil productivity as influenced by the degradation  $\longleftrightarrow$  aggradation processes.

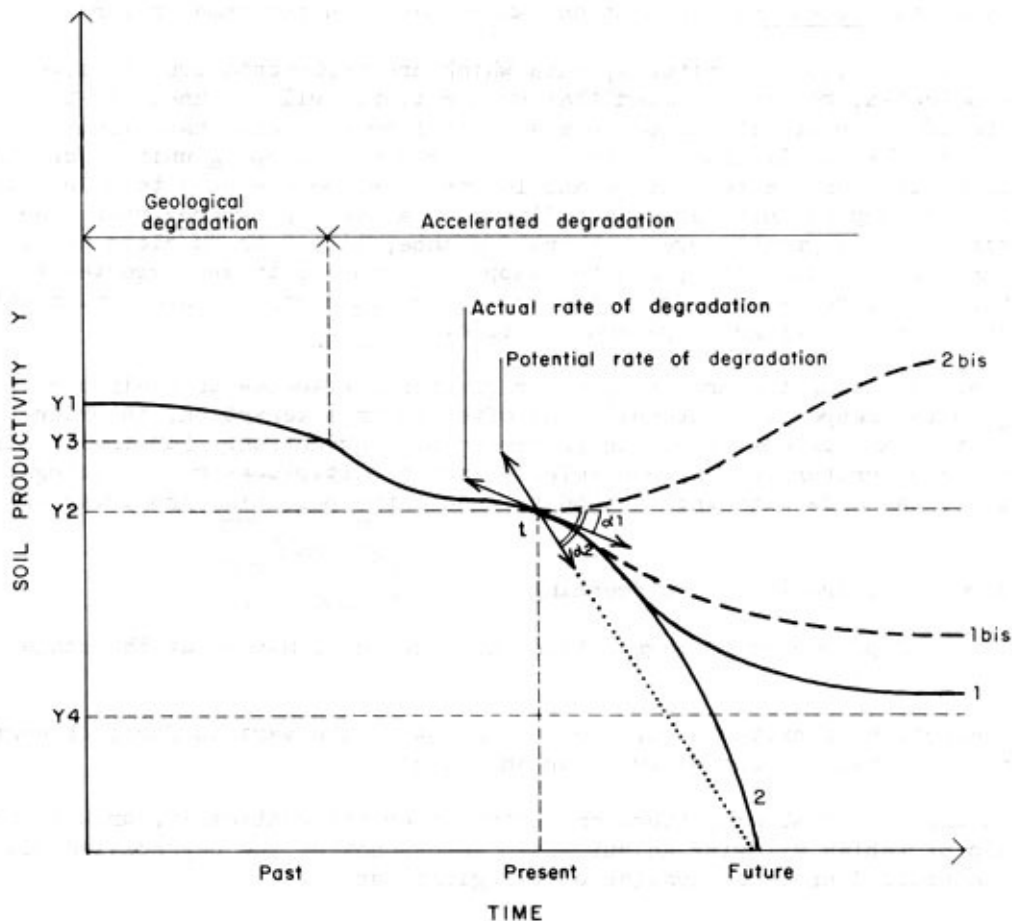


Fig. 1 SOIL PRODUCTIVITY AS INFLUENCED BY THE  
DEGRADATION  $\longleftrightarrow$  AGGRADATION PROCESSES

In the figure this is expressed by the sinuosity of the curve. The graph shows continuous degradation in the past, but aggradation (meaning an increase in the productivity of the soil) could have occurred as well. The following discussion is valid for both cases.

Soil degradation in the past can be called geological degradation until the point in time is reached where human activity influences the soil. The geological degradation can be assessed only by comparison between the initial state  $Y_1$  and the actual state  $Y_2$ . The rate of geological degradation (i.e.  $(Y_1 - Y_2)/\text{time elapsed}$ ) is called normal degradation.

To assess present degradation, two methods can be followed:

1. comparison of the difference between the actual soil productivity level  $Y_2$ , and the level  $Y_3$  representing the level at the time accelerated degradation started;
2. evaluation of the rate of degradation at present, i.e. the slope  $\frac{dy}{dt}$ , or the tangent of the curve at point  $t$  (angle  $\alpha$ ).

In reality the mean rate over a short interval is taken, i.e.  $\frac{\Delta Y}{\Delta t}$ ; an example would be average erosion in t/ha/year over the last five or ten years.

Several factors influence the rate of degradation and they can be divided into two groups, each opposing the other: the vulnerability of the land to certain types of soil degradation, and the human influence. In order to assess actual degradation, land use and management must be taken into account, because they are the prime causes of a change from normal degradation to accelerated degradation (or the reverse).

The assessment of future degradation risks is very difficult since prognosis can easily become invalid because of changes in land use and/or management practices, or environmental factors, e.g. climate. Even if the land use and management are assumed to remain the same, prognosis is difficult because the relationship between degradation and time is not necessarily a straight line, i.e. under the given management, degradation may accelerate or decelerate; indeed the curve often becomes asymptotic to a certain value ( $Y_4$  in the graph), for example: cultivation during numerous years without fertilization (curve 1), or it reaches zero with an acceleration, for instance in the case of erosion of a shallow soil on compact rocks (curve 2). If land use and/or management practices are changed, all kinds of curves can be obtained, e.g. the dashed curve 1bis, which depicts a situation where degradation steadily becomes stabilized, but only after a further decrease in productivity, or the ascending curve 2bis which represents a very well selected land use and management resulting in a rebuilding of the soil productivity.

Given the changing rate of soil degradation (or aggradation) with time, land use and management, certain assumptions must be made in order to arrive at a useful prognosis. Therefore we defined potential degradation, or rather the maximum risk of degradation, as the degradation that will occur under the most severe conditions, that is to say, with the worst possible management, for example: erosion of bare soil. The maximum risk of degradation is then a function of certain relatively stable natural factors, again in the case of erosion, climatic aggressivity, soil erodibility, slope steepness, slope length; it is independent of vegetation cover, land use and management, since these factors are easily modified by human activities. The rate of degradation under these conditions is represented by tangent  $\alpha_2$  in the curve; the future degradation is represented by the dotted line.



Although in most cases the rate of degradation estimated may be higher than the one that will occur in reality, the results allow comparison between the vulnerability to soil degradation of different land areas on a systematic base. By including reduction tables in the explanatory texts with the maps, from which the reduction of soil degradation resulting from various kinds of land uses and management can be read, one can estimate what soil degradation will occur under various kinds of land use.

## 2. PROBLEMS ENCOUNTERED AND ITEMS FOR DISCUSSION

Given the objectives of the project: to map the types of degradation and their present and maximum future rates, the problems are:

### i. Selection of the dominant degradation process in an area.

Is this the process which effects the largest area, is it the most intense process, or is it the process on the agriculturally most important soil?

We have adopted the process on the dominant surface for the proposed legend and the Map of Actual Soil Degradation of Morocco.

### ii. How is soil degradation evaluated quantitatively? In what units should degradation be expressed?

Expression of soil degradation as a decrease in yield/ha/year allows comparison between the effects of one type of soil degradation and another, but in practice this is close to impossible. Other expressions, which are process specific, like soil conductivity in millimhos, pH variation, soil loss in t/ha, etc. do not allow such comparison, and sometimes do not even allow an estimation of the damage to the soil as far as productivity is concerned, e.g. the damage resulting from a soil loss of 30 t/ha/year is not the same for all soil types. Furthermore the damage for one soil type is not comparable if in one field the loss results from sheet erosion and in another the same loss results from gully erosion.

Even when qualitative degradation classifications are used, class limits need to be quantified because what may be regarded in one country as "severe" degradation, may be regarded as "moderate" in another, since qualitative classifications are often subjective and relative.

Direct field measurements and/or monitoring of the processes themselves are the surest way to obtain reliable estimates of the rate of soil degradation. Unfortunately this is not possible at a global scale. Therefore data collected at a few selected locations must be extrapolated to other areas. Since the validity of extrapolation over large distances is questionable, mathematical models can be useful at this point. Another approach would be to rate the various factors according to their status and the weight of their importance. With information gleaned from study of the literature, it is possible to assign values to the important factors for many conditions, but care must still be taken when extrapolating these values.

METHODOLOGY USED TO DETERMINE THE MAXIMUM POTENTIAL AVERAGE ANNUAL SOIL LOSS  
DUE TO SHEET AND RILL EROSION IN MOROCCO

by H.M.J. Arnoldus

To estimate the maximum potential average annual soil loss due to sheet and rill erosion, the Universal Soil Loss Equation <sup>1/</sup> was selected because it is a simple model to operate if the values of the various parameters are known and, in most areas of the world, it gives acceptable results.

In order to arrive at the maximum potential soil loss, the values of the cropping management factor (C - factor) and the erosion control practice factor (P - factor) were taken as unity.

1. EROSION

The erosion factor (R - factor) is traditionally determined by calculating the kinetic energy for each equal intensity period of a rainstorm, times the rainfall amount for that period; then these are summed and multiplied by the maximum 30-minute intensity of the storm. By repeating this over a sufficient number of years an average annual value can be established (Wischmeier, 1959). Later relationships have been established between amounts of rainfall with certain return periods and the average annual rainfall factor value (Wischmeier, 1962; Ateshian, 1974). Nevertheless, it remains necessary to process an enormous amount of data to establish the value of the average annual rainfall factor. Other parameters that can substitute for Wischmeier's factor, like Hudson's  $KE > 25$  - index (Hudson, 1971) and Lal's  $AI_m$  - index (Lal, 1976) also require large amounts of data and considerable calculation time.

In many developing countries too few data exist to calculate any of the indices mentioned above. Therefore, we had to look for an index that could be calculated from readily available data. Fournier's  $p^2/P$  - index (Fournier, 1960) is such since it uses only average monthly and annual precipitation. Tests were run to determine the correlation between Fournier's index and known values of the R - factor for 164 stations in the USA and 14 in West Africa.

---

<sup>1/</sup> According to the Universal Soil Loss Equation, soil loss is a fraction of: rainfall, soil, topography, vegetative cover and management; the equation is written as  $A = RKLSCP$ , in which A is soil loss, R is erosion factor, K is a soil erodibility factor, L and S are topographic factors and C and P are vegetation and management factors.

Correlation coefficients were:

all stations (n = 178);  $r = .74$  for  $R = 534.8 \log p^2/P - 428$

Eastern USA (n = 102)  $r = .69$  for  $R = 18.3 p^2/P - 70.35$  or  
 $\log R = 1.23 \log p^2/P + P_i$

Western USA with exception of Northwest (n = 47)  $r = .46$  for  
 $\log R = 1.19 \log p^2/P + .60$

North Western USA <sup>1/</sup> (n = 15)  $r = .67$  for  $R = 34.96 \log p^2/P - 7$  or  
 $\log R = .67 \log p^2/P + .75$

West African stations (n = 14)  $r = .36$  for  $R = 3.62 \log p^2/P - 329$

From this, it follows that Fournier's index cannot be used as a substitution for the R - factor of the USLE.

A closer look at both indices reveals some basic differences in the underlying philosophy: Wischmeier's index takes all erosion rain into account: it increases with increasing rainfall. Fournier's index does not do so automatically; <sup>2/</sup> for a fixed value for the precipitation in the month with the highest precipitation, the value of Fournier's index decreases when more rain falls in the remaining months, because all other rain only influences the denominator of the index V.

Given this basic difference in philosophy between the two indices, some research has been done to find a new index with a philosophy similar to that underlying Wischmeier's. A modification of Fournier's index proved to be successful; this new index is

$$\sum_1^{12} p_i^2/P$$

in which  $p_i$  is monthly precipitation, and P is annual precipitation.

Correlation coefficients for the same data set are:

all stations (n = 178);  $r = .91$  for  $\log R = 1.93 \log \sum_1^{12} p^2/P - 1.52$

Eastern USA (n = 102);  $r = .89$  for  $R = 6.86 \sum_1^{12} p^2/P - 420$ ;  
 linear-log and log-log relationships have  
 $r = .88$

Western USA with the exception of the North West (n = 47);  $r = .86$   
 for  $\log R = 2.23 \log \sum_1^{12} p^2/P - 1.91$

North Western USA (n = 15)  $r = .80$  for  $R = .66 \sum_1^{12} p^2/P - 3$  and  
 for  $\log R = 2.23 \log \sum_1^{12} p^2/P - .44$

West Africa (n = 14)  $r = .83$  for  $R = 5.44 \sum_1^{12} p^2/P - 416$

<sup>1/</sup> The values of these stations are composed of a rainfall part and a snowmelt runoff part (McCool and Papendick, 1976).

<sup>2/</sup> Since Fournier's prediction equations are based only on rainfall aggressivity and topography, the rainfall factor probably also expresses the regeneration capacity of the vegetation.

Since the correlation equations differ from one region to another, the delineation of homogeneous zones should result in an even better correlation.

The  $\sum_1^{12} p^2/P$  index has also been tried since on data from several states of Brazil covering a 22-year period and for a few stations in Belgium. The correlation between monthly values of the index and values of the R - factor, as calculated by Wischmeier's method, is reported to be very highly significant (Gabriels, 1976, personal communication).

For Morocco, monthly rainfall data for 112 stations were available. The log-log relationship found for West Africa, slightly modified, gives values that correspond very well with the values calculated for a few stations in the Sebou Catchment: 1/ e.g. (in pfs units) Fes: resp. 84 and 84, Taza: resp. 143 and 133 and, Meknes: resp. 104 and 96. The relation used (in metric units) was:

$$R = 1.735 \times 10 (1.50 \log \sum_1^{12} p^2/P - .8188)$$

The result is given on the Erosivity Map attached to this paper (Fig. 1).

Below the  $R = 10$  - isoline no other lines were drawn because the density of the stations was too low. The minimum value found (6), however, was for Ouarzazate (30.56 North, 6.54 West).

## 2. SOIL ERODIBILITY

From a representative population of soils, the soil erodibility was calculated according to the nomograph developed by Wischmeier et al. (1971), adapted to the metric system (Fig. 2) and computerized. Earlier tests had been run to determine the validity of the procedure described by Erickson (1973) for estimating the very fine sand fraction for soils for which only the classical texture classes had been determined. 2/

The correlation coefficients for a sample of almost 200 soils from USA, Canada, Malaysia and Brazil were 0.8 for the whole population and 0.85 for the whole population minus sandy soils. Erickson's relationships were used in estimating the very fine sand fraction for ca 12% of the Moroccan samples. The Soil Erodibility Map of Morocco is attached to this paper as Fig. 3. The boundaries on this map are taken from the FAO/Unesco Soil Map of the World (FAO and Unesco, 1973).

## 3. TOPOGRAPHY

The Soil Map of the World indicates 3 dominant slope classes:

$$a (0 - 8\%), \quad b (8 - 30\%) \quad \text{and} \quad c (> 30\%).$$

---

1/ Atlas du Bassin du Sebou, 1970.

2/ Erickson found for soils in Utah relationships between clay fraction and percentage of very fine sand; the particular relationships are different for each textural class.

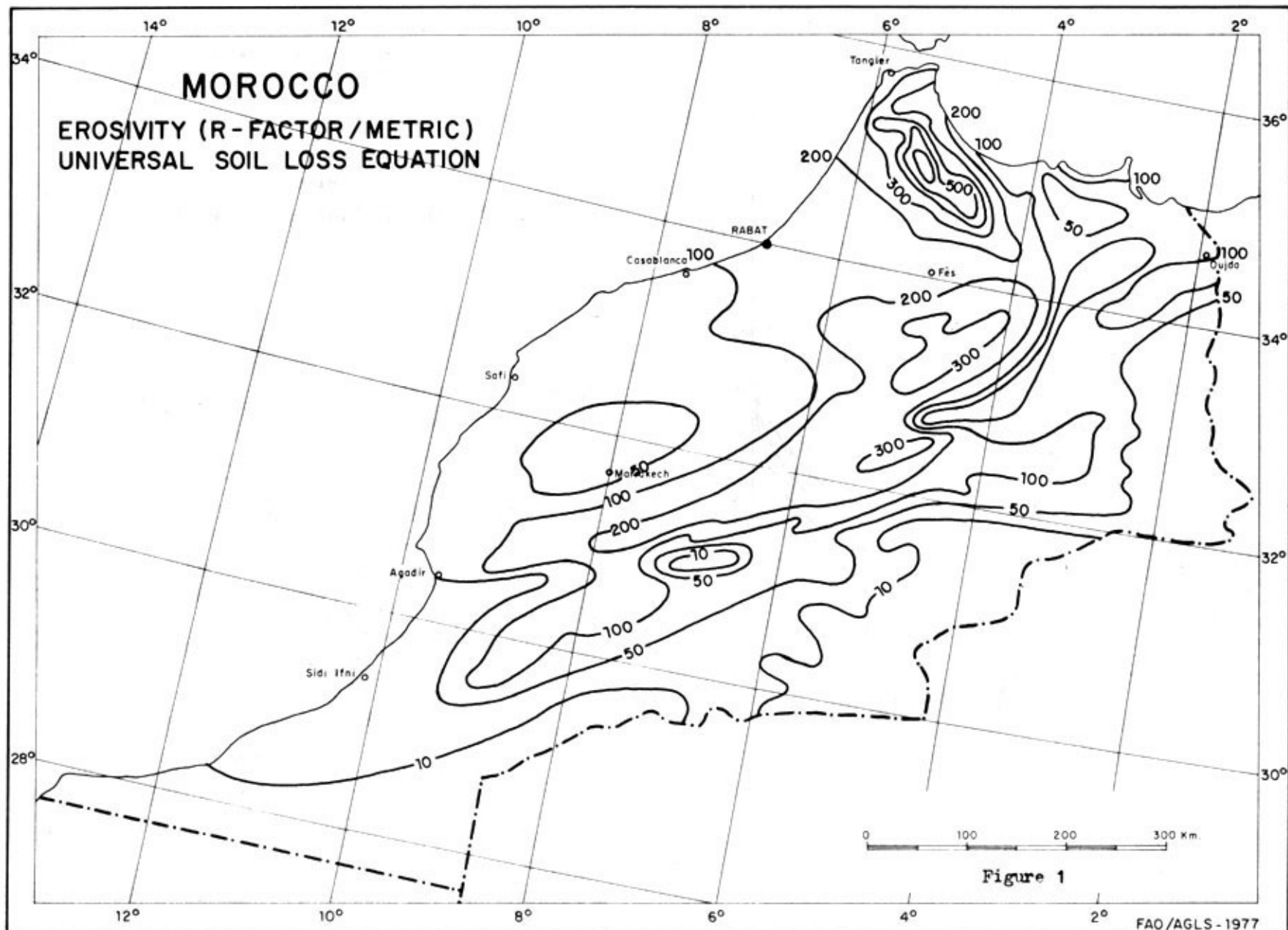
The Topographic Factor Map (Fig. 4) is based upon these slope classes. Soils that, by definition, are situated on very flat terrain, such as fluvisols and gleysols, etc. are assumed to be on slopes of not more than 2%; for those soils an average value of 1% has been chosen and thus the slope gradient factor value (S) is .1. For other soils with slope class a, an average slope of 4% has been assumed, which yields  $S = .35$ . For soils with slope class b, an average value of 20% or  $S = 3.5$  has been assumed, whilst soils with slope class c are supposed to have an average slope of 57.5% or  $S = 10.8$ . Combinations of slope classes are found on the Soil Map of the World: to class ab, an average slope of 10% or  $S = 2.0$  has been assigned, and classes ac and bc have been assumed to have an average slope of 32% or  $S = 8$ .

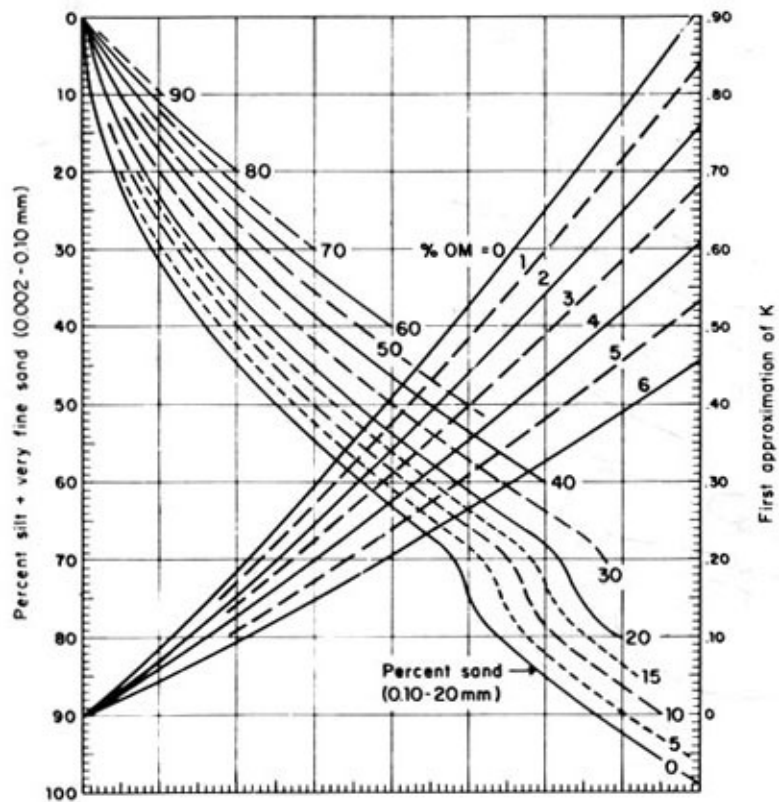
Average slope lengths are difficult to assess on the 1:5 000 000 scale, unless many large scale topography maps can be studied. Therefore, this factor has not been evaluated. The only way it has been taken into account is by assuming that with an increase in slope gradient, the slope length will generally decline. This assumption led to the selection of rather low average slopes to represent the various slope classes.

#### 4. SOIL LOSS

By superposition of the three maps and multiplication of the various values for each unique area, a soil loss map was obtained. From this map, it seemed convenient to establish five soil loss classes: 0 - 5 (metric) tons/ha, 5 - 30 tons/ha, 30 - 200 tons/ha, 200 - 500 tons/ha and 400 - 2 000 tons/ha. It was however, decided to combine the first two classes, since a theoretical maximum value of 30 tons/ha is still low, considering that this soil loss should only occur if there is no vegetation and no control practices are applied.

From the final map (Fig. 5) it seems that, at least in Morocco, topography is a factor of overriding importance, with erosivity as a factor of secondary importance. Variation in soil erodibility seems to be a minor factor at country level and when only a few classes are used.





**SOIL-ERODIBILITY NOMOGRAPH**  
(METRIC SYSTEM)

AFTER WISCHMEIER, JOHNSON AND CROSS (1971)

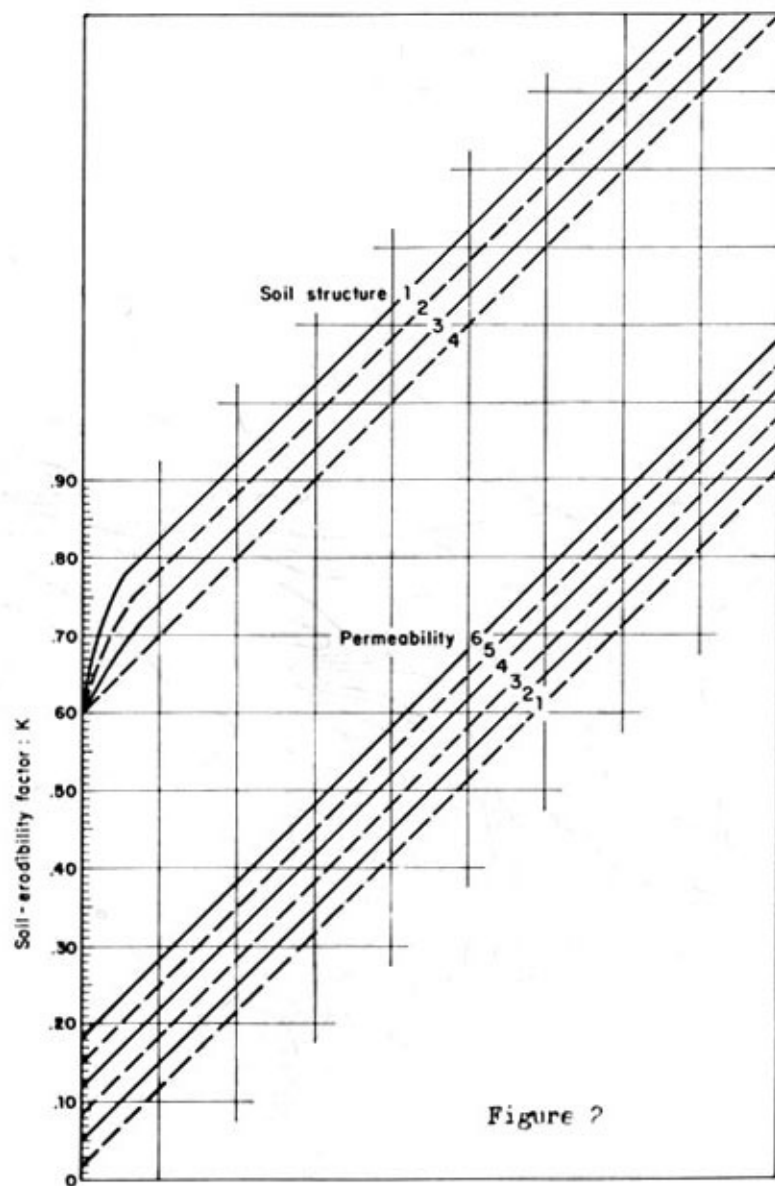
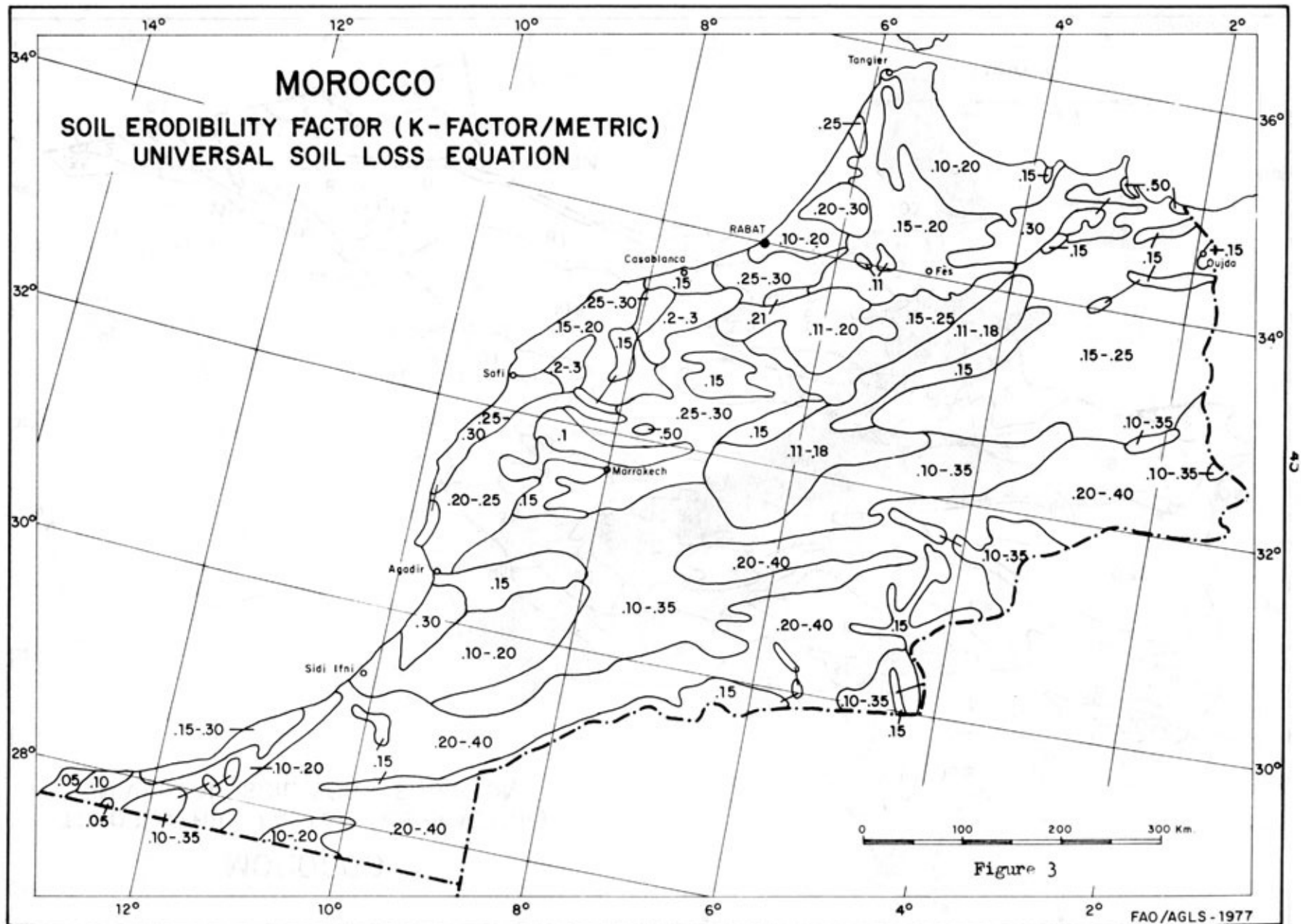
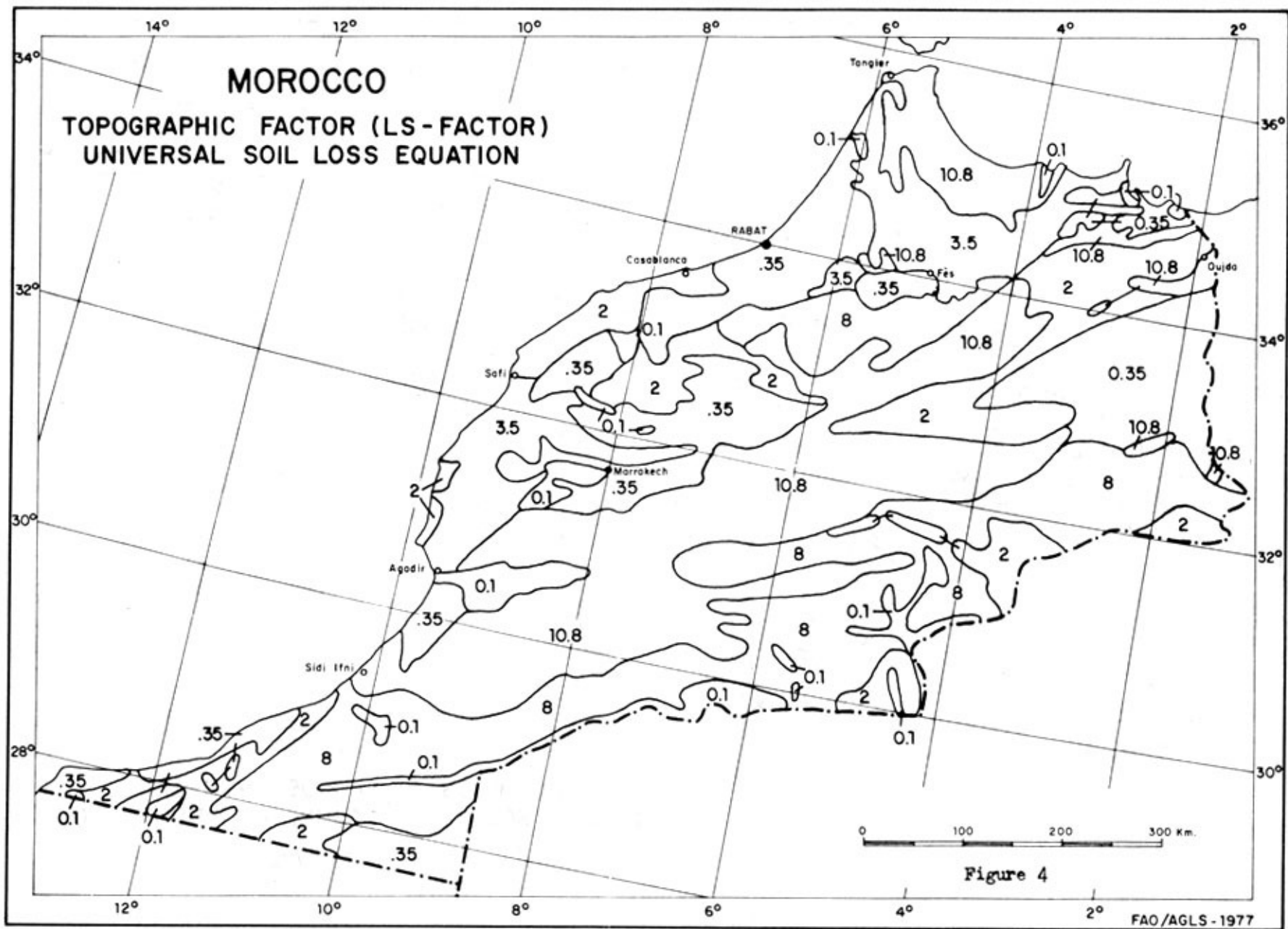


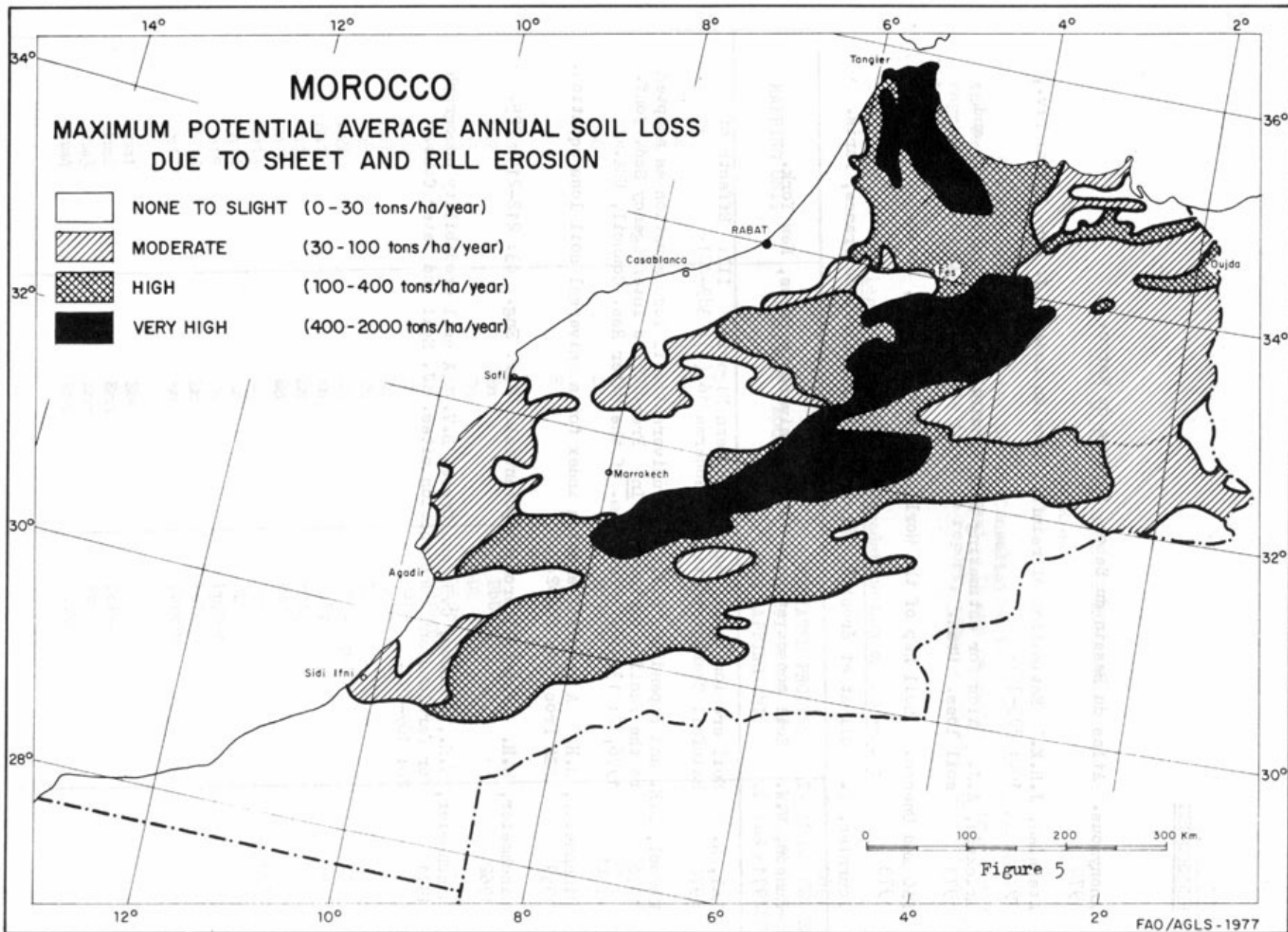
Figure 2

FAO/AGL - July 1976









## REFERENCES

- Anonymous. Atlas du Bassin du Sebou, Royaume du Maroc.  
1970
- Ateshian, J.H.K. Estimation of rainfall erosion index. J. Irr. Drain. Div.,  
1974 100: 293-307.
- Erickson, A.J. Aids for estimating soil erodibility - "K" value class and  
1973 soil loss. Utah.
- FAO and Unesco. Soil Map of the World, Sheet VI, Unesco, Paris.  
1973
- Fournier, F. Climat et érosion. Presses Universitaires de France, Paris.  
1960
- Hudson, N.W. Soil conservation. Cornell University Press, New York.  
1971
- Lal, R. Soil erosion on Alfisols in Western Nigeria. III: Effects of  
1976 Rainfall Characteristics. Geoderma 16 (5): 389-401.
- McCool, D.K. and Papendick, R.I. The universal soil loss equation as adapted  
1976 to the Pacific Northwest. In: Proc. Third Inter-Agency Sed. Conf.  
1976, 2: 135-147. Sed. Com. of the Water Res. Council, USA.
- Wischmeier, W.H. A rainfall erosion index for a universal soil loss equation.  
1959 SSSA Proc. 23: 246-249.
- Wischmeier, W.H. Rainfall erosion potential. Agr. Eng., 43: 212-215, 225.  
1962
- Wischmeier, W.H., Johnson, C.B. and Cross, B.V. A soil erodibility nomograph  
1971 for farmland and construction sites. J. Soil and Water Cons.  
26: 189-193.

## SOIL DEGRADATION MAP OF MOROCCO

by J. Riquier

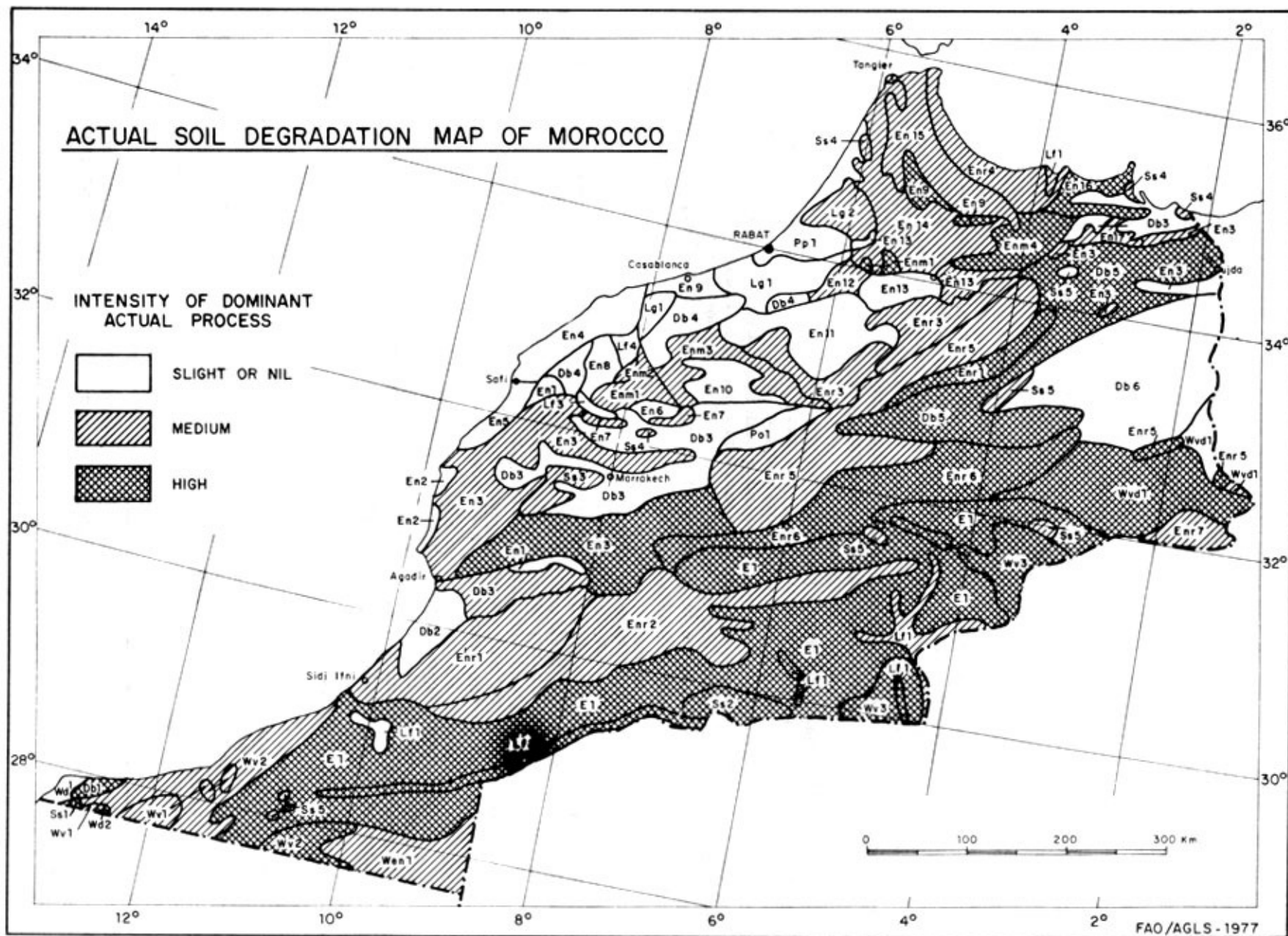
The map presented at the Expert Consultation was drawn in conformity with the legend given in the Background Document. It was presented in colour but to reproduce it in black and white for this report, some slight changes have had to be made.

Legend to the Soil Degradation Map of Morocco 1/

MAPPING UNIT	DOMINANT PROCESS	ASSOCIATED PROCESS AFFECTING 20% OF THE MAPPING UNIT	INCLUDED PROCESSES AFFECTING 5-20% OF THE MAPPING UNIT
Db1	Db	Wd	Ss
Db2	Db	PoWd	
Db3	Db	EnWd	
Db4	Db		
Db5	Db	DcPoWv	Ss
Db6	Db	EnWdPo	LfSs
E1	E	WSDc	Lf
En1	En		
En2	En	DbDc	
En3	En	Db	
En4	En	WdPo	Ss
En5	En	WdPoDb	
En6	En	WdPo	
En7	En	DcPp	
En8	En	Lg	
En9	En	Db - PpPo	Lg
En10	En	PoPp	Db
En11	En	PpLg	Db
En12	En	Po	
En13	En	Pp	LgDb
En14	En	Db	LgSs
En15	En	PpDbEn	
En16	En	PoDc	
En17	En	DbPoDc	
Enm1	Enm		
Enm2	Enm	DcPo	
Enm3	Enm	Po	
Enm4	Enm	DbPo	

MAPPING UNIT	DOMINANT PROCESS	ASSOCIATED PROCESS AFFECTING 20% OF THE MAPPING UNIT	INCLUDED PROCESSES AFFECTING 5-20% OF THE MAPPING UNIT
Ehr1	Ehr	PoDb	
Ehr2	Ehr	Po	
Ehr3	Ehr	Dc	
Ehr4	Ehr	PpDb	
Ehr5	Ehr		
Ehr6	Ehr	DbPoDc	
Ehr7	Ehr	WvDcPo	
Lf1	Lf	Ss	
Lf2	Lf	SsWv	
Lf3	Lf	LgDb	
Lf4	Lf	DbPo	
Lg1	Lg	Db	
Lg2	Lg	SsDb	Sa
Po1	Po	WdLg	
Pp1	Pp	Lg	
Ss1	Ss	Wd	
Ss2	Ss	LfW	
Ss3	Ss	DbEn	
Ss4	Ss	Lg - LgDb	
Ss5	Ss	DbLf	
Wd1	Wd	Po	DbSs
Wd2	Wd		
Wv1	Wv	EnDb	
Wv2	Wv	DbEnSs - DbEn	DcLf
Wv3	Wv	EnDc	
Wvd1	Wvd	EnDcPo	

1/ For the precise meaning of the symbols, see page 34.



## CRITERIA FOR ASSESSING WIND EROSION 1/

by E.L. Skidmore

## 1. INTRODUCTION

Wind erosion is serious in many parts of the world. General areas most susceptible to wind erosion on agricultural land include much of North Africa and the Near East, parts of southern and eastern Asia, Australia and southern South America, and the semi-arid and arid portions of North America (FAO, 1960). In addition, such agricultural areas as the Siberian Plain and others in the USSR are potentially susceptible to wind erosion.

Soil erosion by wind, generally thought to be limited to semi-arid and arid areas, can be a problem wherever: 1) the soil is loose, dry, and reasonably finely divided; 2) the soil surface is smooth and vegetative cover is absent or sparse; 3) the field is large; and 4) the wind is sufficiently strong to move soil. These conditions are likely to prevail in semi-arid and arid areas, where precipitation is inadequate or where the climatic vagaries from season to season or year to year prevent maintaining crops or residue cover on the land; however, they sometimes exist in subhumid and even humid areas.

Wind erosion damages in several ways. It physically removes from the field the most fertile portion of the soil, thereby lowering productivity (Daniel and Langham, 1936; Lyles, 1975). Some eroded soil enters the atmospheric dustload (Hagen and Woodruff, 1973), which obscures visibility, pollutes the air, causes traffic hazards, fouls machinery, and imperils animal and human health. Blowing soil also fills road ditches and irrigation canals, reduces seedling survival and growth, lowers the marketability of many vegetable crops, and increases the susceptibility of plants to disease and to the transmission of some plant diseases.

This paper presents criteria for assessing wind erosion on a regional basis by first assessing it on a field basis. Also, the regional wind erosion hazard can be evaluated based on the erodibility of the soil and meteorological conditions conducive to soil detachment and transport.

## 2. ASSESSING WIND EROSION ON A FIELD BASIS

Studies to understand the mechanics of the wind erosion process to identify major factors influencing wind erosion, and to develop wind erosion control methods led to the development of a wind erosion equation (Chepil and Woodruff, 1963; Woodruff and Siddoway, 1965). The equation was designed to determine the average potential erosion from a particular field and the field conditions necessary to reduce potential erosion to a specified amount.

---

1/ Contribution from the Agricultural Research Service, U.S. Department of Agriculture, in cooperation with the Kansas Agricultural Experiment Station. Dept. of Agronomy Contribution No. 1647-a.

It is assumed that the reader is familiar with the wind erosion equation, therefore, only a brief description will be given here. More detail has been given by Chepil and Woodruff, 1963; Woodruff and Siddoway, 1965; Skidmore and Woodruff, 1968; Skidmore et al., 1970; Skidmore, 1976.

The general functional relationship between the dependent variable, E (the potential average annual soil loss in tons per hectare), and the independent variables is:  $E = f(I, K, C, L, V)$ , where I is a soil erodibility index; K is a soil-ridge roughness factor; C is a climatic factor; L is field length along the prevailing wind erosion direction; and V is equivalent quantity of vegetative cover.

Relations among variables are complex, and a single equation that expresses E as a function of the independent variables has not been devised. The equation was solved in a stepwise procedure involving graphical solutions until a computer solution was developed to simplify the procedure (Fisher and Skidmore, 1970; Skidmore et al., 1970).

The solution of the wind erosion equation gives the amount of erosion expected, in tons/ha/year, from a given agricultural field.

The information needed to assess potential soil loss from a field is: (1) percentage of soil aggregates exceeding 0.84 mm; (2) length and steepness of windward knoll slopes; (3) ridge height and spacing; (4) climatic factor; (5) angle of deviation of prevailing wind erosion direction from right angles to field strip; (6) preponderance of wind erosion forces in prevailing wind erosion direction; (7) height of wind barrier, if any; (8) field width; (9) quantity of vegetative cover; and (10) type of vegetative cover. Information for items 4 and 6 and for determining item 5 can be obtained by month for many USA locations from the literature (Skidmore and Woodruff, 1968). The percentage of soil aggregates exceeding 0.84 mm (item 1) can best be obtained by dry sieving; however, in practice, the percentage is often determined from wind erodibility groups based on soil type or predominant soil textural class (Hayes, 1972). Other factors can be measured in the field or estimated by comparing field conditions with similar field conditions for which the factors have been measured.

### 3. ASSESSING WIND EROSION ON A COUNTY AND REGIONAL BASIS

The wind erosion equation can be used as a basis for assessing wind erosion on an area, such as a county, larger than an individual field.

In the USA, pertinent data can be obtained from several sources. Annual area cropped and yield data for each major crop are available by county from "Agricultural Statistics", published by state boards of agriculture. Total land area by county is available from the Conservation Needs Inventory; soil data are available from soil surveys; and climatological data are available from the National Climatological Record Center. Using those data and the wind erosion equation, one can estimate potential average annual soil loss for a county or a group of counties.

Consider Ellis County, Kansas, for example. Table 1 gives the major soils in the county, the areal extent of those soils, their approximate erodibility based on soil textural classification, and an estimate of the average annual potential soil loss from each of the soils. For this calculation, it was assumed that the field is wide, smooth and bare of vegetation. The grain yield of major crops was estimated from the average county yield of that crop, multiplied by a factor that compares the estimated capability of a particular soil with other soils in the county to produce a given crop. The straw or stover was estimated from grain yield. On the average, winter wheat produced 1.7 quintals of straw for each quintal of grain. Sorghum and maize produced about equal grain and stover.



Table 1

STRAW RESIDUE PRODUCED ON THE VARIOUS SOILS IN ELLIS COUNTY, KANSAS,  
AND AMOUNT OF STRAW NEEDED ON THE SOIL TO CONTROL WIND EROSION TO 11.2 t/ha/yr

SOIL	AREA 1000 ha	ERODIBILITY t/ha/yr	SOIL LOSS	CONTINUOUS WHEAT			
				GRAIN YIELD	STRAW PRODUCED	STRAW NEEDED <sup>1/</sup>	SURPLUS STRAW <sup>2/</sup>
				q/ha			
Anselmo Fine Sandy Loam	0.8	193.0	96.4	16.8	28.5	16.3	-2.1
Armo Loam 1-3%S	2.9	193.0	96.3	16.1	27.4	16.3	-2.6
Armo Loam 3-7%S	3.4	193.0	96.3	14.1	24.0	16.3	-4.3
Armo Loam 3-7%SE	1.0	193.0	96.3	12.1	20.6	16.3	-6.0
Campus-Carlson Complex	4.9	150.0	75.1	12.1	20.6	14.5	-4.2
Corinth Silty Clay Loam 1-3%S	0.2	193.0	96.3	13.4	22.8	16.3	-4.9
Corinth Silty Clay Loam 3-7%S	1.9	193.0	96.3	11.4	19.4	16.3	-6.6
Crete Silty Clay Loam 0-1%S	3.2	193.0	96.3	21.5	36.5	16.3	2.0
Crete Silty Clay Loam 0-1%TSV	0.2	193.0	96.3	18.2	30.8	16.3	-0.9
Detroit Silt Loam	1.5	142.0	70.8	20.2	34.3	14.2	2.0
Eltree Silt Loam 0-1%S	0.8	142.0	70.8	22.9	38.8	14.2	5.2
Eltree Silt Loam 1-3%S	2.6	142.0	70.8	21.5	36.6	14.2	4.1
Eltree Silt Loam 3-7%S	2.1	142.0	70.8	20.2	34.3	14.2	3.0
Harney Silt Loam 0-1%S	17.5	142.0	70.8	21.5	36.6	14.2	4.1
Harney Silt Loam 1-3%S	14.6	142.0	70.8	20.2	34.3	14.2	3.0
Harney Silt Loam 3-7%S	4.1	142.0	70.8	17.5	29.7	14.2	0.7
Harney Silty Clay Loam 2-5%SE	8.1	157.0	78.4	16.1	27.4	14.7	-1.0
Harney Armo Complex 3-7%SE	8.9	128.0	63.9	14.8	25.1	13.4	-0.9
Harn.-Carls. Silt Loam 0-1%S	2.0	142.0	70.8	18.2	30.8	14.2	1.2
Harn.-Carls. Silt Loam 1-3%S	18.7	142.0	70.8	17.5	29.7	14.2	0.7
Harn.-Wak. Silt Loam 0-1%S	0.7	142.0	70.8	17.5	29.7	14.2	0.7
Harn.-Wak. Silt Loam 1-3%S	6.5	142.0	70.8	16.8	28.6	14.2	0.1
Holdrege Silt Loam 0-1%S	0.5	142.0	70.8	22.9	38.8	14.2	5.2
Holdrege Silt Loam 1-3%S	1.2	142.0	70.8	21.5	36.6	14.2	4.1
Hord Silt Loam	2.8	142.0	70.8	22.9	38.8	14.2	5.2
McCook Fine Sandy Loam	0.4	143.0	96.3	20.2	34.3	16.3	0.9
McCook Silt Loam	2.3	142.0	70.8	16.8	28.6	14.2	0.1
Mento Silt Loam 0-1%S	0.3	142.0	70.8	15.5	26.3	14.2	-1.1
Mento Silt Loam 1-3%S	8.5	142.0	70.8	13.5	22.8	14.2	-2.8
Mento Silty Clay Loam	1.1	157.0	78.4	12.1	20.6	14.7	-4.4
Mento Soils	6.4	145.0	72.2	10.8	18.3	14.2	-5.1
Munjor Sandy Loam	1.4	193.0	96.3	16.1	27.4	16.3	-2.6
New Cambria Silty Clay	0.7	193.0	96.3	17.5	29.7	16.3	-1.5
Boxbury Silt Loam	6.8	142.0	70.8	22.9	38.8	14.2	5.2
Boxbury Silt Loam Fre. Flded	11.2	142.0	70.8	16.8	28.6	14.2	0.1
Wakeen Silt Loam 1-3%S	2.4	142.0	70.8	14.8	25.1	14.2	-1.7
Wakeen Silt Loam 1-3%SE	0.2	142.0	70.8	10.1	17.1	14.2	-5.7
Wakeen Silt Loam 3-7%S	4.2	142.0	70.8	11.4	19.4	14.2	-4.5
Wann Loam	1.4	142.0	70.8	16.8	28.6	14.2	0.1

<sup>1/</sup> Assumes straw is left flat.

<sup>2/</sup> Assumes 50% of straw is buried by tillage.

To further assess the erosion in the county, one must know the distribution of the various crops grown on each soil. For example, what portions of the 800-ha Anselmo fine sandy loam are planted to wheat, sorghum, or maize and what portions are in fallow? In addition, what are the dominant tillage and residue management practices on that soil?

But let us consider an area even larger than a county. In the USA a convenient size for assessing wind erosion is the land resource area (LRA), composed of land resource units, each usually several thousand hectares in extent and characterized by a particular pattern of soil (including slope and erosion), climate, water resources, land use, and type of farming. (Major land resource areas consist of geographically associated land resource units; major land resource regions consist of geographically associated major land resource areas, Austin, 1972.)

For example, let us consider the counties of LRA 72 in Kansas. This area contains 24 counties with a total land area of  $5.5 \times 10^6$  ha ( $13.6 \times 10^6$  acres) and  $3.9 \times 10^6$  ha ( $9.7 \times 10^6$  acres) of cropland. The major crops (with area and yield of each) are shown in Table 2. The amount of residue produced per unit land area was estimated from grain yield data, assuming that the residue/grain ratio is 1.0 for maize and sorghum and 1.7 for wheat. Approximately 10% of the wheat planted was not harvested.

Table 2 LAND RESOURCE AREA 72 - 24 KANSAS COUNTIES -  
1975-76 YIELD DATA

CROP	AREA	YIELD	RESIDUE <sup>2/</sup>	POTENTIAL SOIL LOSS <sup>1/</sup>		
				1	2	3
	1 000 ha	— q/ha —		— t/ha/yr —		
Irrigated maize	652	67	67	75	22	16
Sorghum	402	35	35	75	43	31
Hay	137	67	0	0	0	0
Continuous wheat	70	13	23	52	34	25
Fallow wheat	1 273	19	33	40	22	16
Fallow (no crop)	1 273	0	0	75	29	18
Wheat (PNH) <sup>3/</sup>	123	0	0	75	45	34
	<u>3 931</u>					

TOTAL LAND INVENTORY AREA: 5 502 700 ha

<sup>1/</sup> See text for conditions.

<sup>2/</sup> Estimated amount of residue after harvest.

<sup>3/</sup> PNH = Planted but not harvested.

Average annual soil loss was estimated by the wind erosion equation (Woodruff and Siddoway, 1965) for three combinations of conditions: 1) Wide field, 1/4 bare of residue and with rough surface. 2) Wide field with semi-ridged surface - 1/4 of maize and sorghum residue left standing (30 cm tall), 1/4 flattened on the surface, and the other 1/2 removed; 1/4 of continuous wheat residue on surface plus protective value of growing wheat (seedling and stooling) equivalent to 1/10 residue produced; fallow with 1/5 of the residue produced remaining on surface; wheat (planted, not harvested) with residue equivalent to 1/4 of residue produced in continuous wheat production. 3) Same conditions as 2 except that the field is 200 m (660 ft) wide. The means for the area were 86 and 78, respectively for erodibility I and climatic factor C.

The average annual soil loss for the cropland in the 24-county area, according to the relationship of the wind erosion equation, was 60, 27, and 18 metric tons per hectare for the three levels of assumed management. Most of the non-cropland is rangeland. Assuming that the non-cropland is non-erosive, the average soil loss for the total inventory land area became 43, 20, and 13 t/ha/yr, respectively, for the three levels of management. That corresponds to 588, 274, and 184 million metric tons of soil.

#### 4. ASSESSING WIND EROSION HAZARD FROM BASIC SOIL ERODIBILITY AND CLIMATIC POTENTIAL TO CAUSE WIND EROSION

Two (erodibility and climatic factor) of the five independent variables of the wind erosion equation are basic to the soil and climate of the region and are less alterable by management than are the others. Used together, soil erodibility index and climatic factor show promise for use in assessing wind erosion hazard.

##### Erodibility Index

Soil erodibility (ease of detachment and transport by wind) is a primary variable affecting wind erosion. From wind tunnel tests, Chepil (1950) determined relative erodibilities of soils (reasonably free from organic residues) as a function of apparent specific gravity and proportions of dry soil aggregates in various sizes. Since then, the non-erodible soil fraction greater than 0.84 mm, as determined by dry sieving, has been used to indicate erodibility of soil by wind. In an early version of the wind erosion equation (Chepil and Woodruff, 1954), erodibility was one of three major factors developed from results obtained principally with a portable wind tunnel (Zingg, 1951a, 1951b; Zingg and Woodruff, 1951).

A dimensionless soil erodibility index, I, (Chepil, 1958; Chepil and Woodruff, 1959) was based on the non-erodible fraction (percentage of clods exceeding 0.84 mm diameter). The quantity of soil eroded in a tunnel is governed by the tunnel's length and other characteristics; therefore, erodibility was expressed on a dimensionless basis so that for a given soil and surface condition, the same relative erodibility value would be obtained regardless of wind tunnel characteristics (Chepil, 1960). The soil erodibility index was expressed as

$$I = X_2/X_1 \quad (1)$$

where  $X_1$  is quantity eroded from soil containing 60 percent of clods exceeding 0.84 mm, and  $X_2$  is the quantity eroded under the same set of conditions from soil containing any other proportions of clods exceeding 0.84 mm. Soil erodibility index, I, gave a relative measure of erodibility, but actual soil loss by wind was not known.

---

1/ Wide field means that any further increase in width would not increase erosion hazard. This condition usually occurs for a field between 500 and 1 000 metres.

Therefore, during the severe wind erosion of 1954-56 (1 January through 30 April) 69 fields were studied in western Kansas and eastern Colorado to determine the quantity of soil loss for any field erodibility as determined from various field conditions (Chepil, 1960). The average depth of soil eroded usually was indicated by depth to which wheat crowns and roots were exposed.

Seasonal loss was converted to annual soil loss, and relative field erodibility for each field was determined by procedures previously outlined (Chepil, 1959; Chepil and Woodruff, 1954; Chepil and Woodruff, 1959). The relation between annual soil loss and relative field erodibility was

$$Y = aX^b - 1/cd^X \quad (2)$$

where Y is annual soil loss (tons per acre); X is dimensionless relative field erodibility; and a, b, c, and d are constants equal to 140, 0.287, 0.01525 and 1.065, respectively. Chepil (1960) recognized that inaccuracies in measuring relatively small annual soil losses from depth of soil removal made conversion of relative field erodibility to annual soil loss by equation 2 highly approximate.

When a field is smooth, bare, wide, unsheltered, and noncrusted, its relative erodibility is equivalent to the soil erodibility index defined by equation (1). When I from equation (1) is substituted for X in equation (2), potential annual soil loss in tons per acre is obtained.

Although percentages of non-erodible fractions vary seasonally with management practices and chemical composition of soil, erodibility is strongly influenced by particle size distribution of the soil. Sands, for example, have insufficient fine material to cement the grains into larger aggregates, and much of the soil mass is single grained and, consequently, very erodible. Further research is needed before we can define erodibility precisely as a function of soil, climate, and management; however, we can reasonably estimate a soil's erodibility based on the textural classification of the soil. Therefore, knowledge of surface soil texture distribution in a region provides a basis for estimating susceptibility of the soil to erosive winds.

#### Climatic Factor

The climatic factor is an index of the average rate at which soil is moved by wind as influenced by moisture content in surface soil particles and average wind-speed. Chepil *et al.* (1962) proposed a climatic factor to determine average annual soil loss for climatic conditions other than those pertaining when the relationship between wind tunnel and field erodibility was obtained.

The soil moisture term of the climatic factor of the wind erosion equation was developed on the basis that erodibility of a soil varies inversely with the equivalent moisture in surface soil particles (Chepil, 1956). Effective moisture of the surface soil particles was assumed to vary as indicated by the Thornthwaite (1931) P-E index developed to evaluate precipitation effectiveness. The P-E index is the sum of 12 monthly precipitations divided by evaporation ratios.

The soil-moisture term of the climatic factor needs refining. The current procedures assume that effective moisture of the surface soil particles varies with the P-E index, but surface moisture content is transient (Idso *et al.*, 1974; Jackson, 1973; Jackson *et al.*, 1973). Drying rate and dryness of particles are functions of hydraulic soil properties and climatic variables not fully reflected in the P-E index. These relationships need examining and then relating to the wind erosion process.

The windspeed term of the climatic factor is based on the assumption that rate of soil movement is proportional to windspeed cubed. Several researchers (Bagnold, 1943; Chepil, 1945; Zingg, 1953) have reported that when windspeeds exceed those required barely to move the soil, the soil-movement rate is directly proportional to friction velocity cubed. Over a specified surface, windspeed and friction velocity are proportional.

The long-term average windspeed and soil moisture index at Garden City, Kansas, was the reference for the climatic factor. It was expressed as

$$C = 100 u^3 / 2.9 (P-E)^2$$

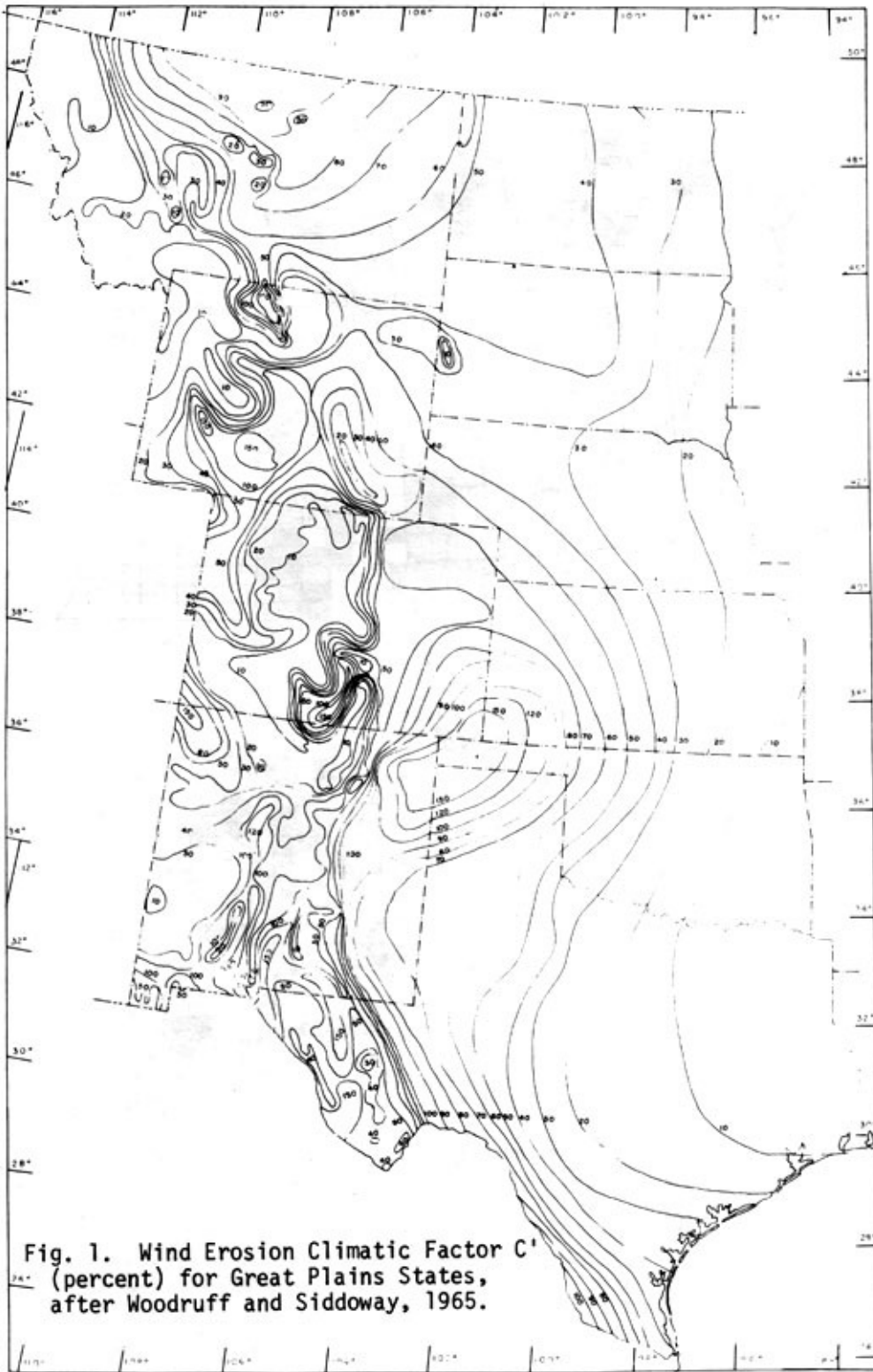
where  $u$  is the corrected mean annual windspeed for a standard height of 30 feet,  $P-E$  is an index of equivalent moisture in surface soil particles, and 2.9 is the approximate average value of  $u^3 / (P-E)^2$  for Garden City, Kansas.

Monthly windspeeds are used in lieu of annual windspeeds to determine monthly  $C$  values for calculating erosion when plant damage of certain periods of the year is the major interest (Woodruff and Armbrust, 1968). Climatic-factor maps have been prepared for the major wind erosion areas of the USA (Skidmore and Woodruff, 1968). Figures 1 and 2 show that in 1975-76 in the Great Plains the climatic factor and wind erosion damage to cropland were similar.

The product of an appropriate climatic factor and soil erodibility index indicate intensity of wind erosion hazard (WEH) for wide, smooth fields bare of vegetation. Suppose the land in a region is divided into  $n$  erodibility groups, each with area  $A_i$  and associated erodibility index  $I_i$  and climatic factor  $C_i$ . Then the mean wind erosion hazard for that region would be

$$WEH = \frac{\sum_{i=1}^n A_i I_i C_i}{\sum_{i=1}^n A_i}$$

As other data such as amount and kind of vegetative cover become available, they can be included in the calculation. Also, because  $I$  and  $C$  vary seasonally and yearly, it may be desirable to calculate probabilities.



CROPLAND DAMAGE BY WIND  
1975 -76

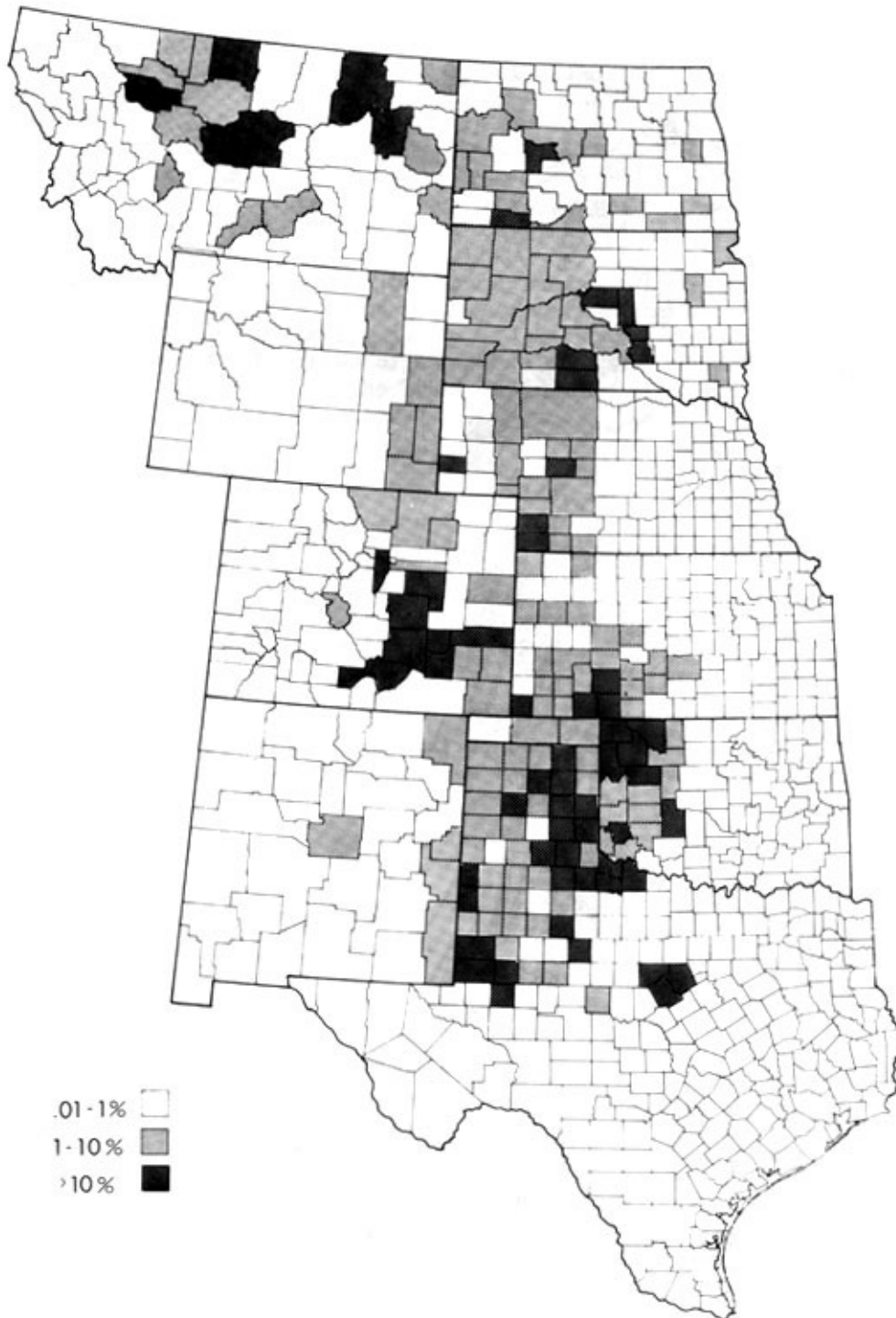


Fig. 2. Percentage of cropland damaged by wind erosion, summarized from data reported by U.S. Dept. of Agriculture, Soil Conservation Service.

## REFERENCES

- Austin, M.E. Land resource regions and major land resource areas of the  
1972 United States. Agriculture Handbook 296, USDA Soil Conservation  
Service, 82 p.
- Bagnold, R.A. The physics of blown sand and desert dunes. William Morrow,  
1943 New York, N.Y., 265 p.
- Chepil, W.S. Dynamics of wind erosion: I. Nature of movement of soil by  
1945 wind. Soil Science 60:305-320.
- Chepil, W.S. Properties of soil which influence wind erosion: II. Dry  
1950 aggregate structure as an index of erodibility. Soil Science  
69:403-414.
- Chepil, W.S. Influence of moisture on erodibility of soil by wind.  
1956 Soil Sci. Soc. Amer. Proc. 20:288-292.
- Chepil, W.S. Soil conditions that influence wind erosion. USDA Tech.  
1958 Bul. No. 1185, 40 p.
- Chepil, W.S. Wind erodibility of farm fields. J. Soil Water Conserv.  
1959 14:214-219.
- Chepil, W.S. Conversion of relative field erodibility to annual soil loss  
1960 by wind. Soil Sci. Soc. Amer. Proc. 24:143-145.
- Chepil, W.S., Siddoway, F.H. and Armbrust, D.V. Climatic factor for  
1962 estimating wind erodibility of farm fields. J. Soil Water Conserv.  
17:162-165.
- Chepil, W.S. and Woodruff, N.P. Estimations of wind erodibility of field  
1954 surfaces. J. Soil Water Conserv. 9:257-265, 285.
- Chepil, W.S. and Woodruff, N.P. Estimations of wind erodibility of farm  
1959 fields. USDA Prod. Res. Rpt. No. 25, 21 p.
- Chepil, W.S. and Woodruff, N.P. The physics of wind erosion and its control.  
1963 Advances in Agron. 15:211-302.
- Daniel, H.A. and Langham, W.H. The effect of wind erosion and cultivation  
1936 on the total nitrogen and organic matter content of soils in the  
Southern High Plains. J. Amer. Soc. Agron. 28:587-596.
- Fisher, P.S. and Skidmore, E.L. WEROS: A Fortran IV program to solve the  
1970 wind erosion equation. USDA, ARS 41-174, 13 p.
- Food and Agricultural Organization of the United Nations. Soil erosion by  
1960 wind and measures for its control on agricultural lands. Agric.  
Development Paper 71, FAO, Rome.
- Hagen, L.J. and Woodruff, N.P. Air pollution from duststorms in the Great  
1973 Plains. Atm. Environ. 7:323-332.
- Hayes, W.A. Designing wind erosion control systems in the Midwest Region.  
1972 RTSC Technical Note, Agronomy-LI-9.



- Idso, S.B., Jackson, R.D., Reginato, R.J., Kimball, B.A. and Nakayama, F.S.  
1975 The dependence of bare soil albedo on soil water content. *Appl. Meteorol.* 14:109-113.
- Jackson, R.D. Diurnal changes in soil water content during drying. In:  
1973 *Field Soil Water Regime*. R.R. Bruce (Ed.), Soil Sci. Soc. Amer. Special Pub. No. 5.
- Jackson, R.D., Kimball, B.A., Reginato, R.J. and Nakayama, F.S. Diurnal  
1973 soil-water evaporation: Time-depth-flux patterns. *Soil Sci. Amer. Proc.* 37:505-509.
- Lyles, L. Possible effects of wind erosion on soil productivity. *J. Soil*  
1975 *Water Conserv.* 30:279-283.
- Skidmore, E.L. A wind erosion equation: development, application, and  
1976 limitations. ERDA Symposium Series 38, *Atmosphere-Surface Exchange of Particulate and Gaseous Pollutants (1974)*, pp. 452-456.
- Skidmore, E.L., Fisher, P.S. and Woodruff, N.P. Wind erosion equation:  
1970 computer solution and application. *Soil Sci. Soc. Amer. Proc.* 34:931-935.
- Skidmore, E.L. and Woodruff, N.P. Wind erosion forces in the United States  
1968 and their use in predicting soil loss. *USDA, ARS, Agr. Handbook No. 346*, 42 p.
- Thorntwaite, C.W. Climates of North America according to a new classification.  
1931 *Geog. Rev.* 25:633-655.
- Woodruff, N.P. and Armbrust, D.V. A monthly climatic factor for the wind  
1968 erosion equation. *J. Soil Water Conserv.* 23:103-104.
- Woodruff, N.P. and Siddoway, F.H. A wind erosion equation. *Soil Sci. Soc. Amer. Proc.* 29:602-608.  
1965
- Zingg, A.W. Evaluation of erodibility of field surfaces with a portable  
1951a wind tunnel. *Soil Sci. Soc. Amer. Proc.* 15:11-17.
- Zingg, A.W. A portable wind tunnel and dust collector developed to evaluate  
1951b the erodibility of field surfaces. *Agron. J.* 43:189-191.
- Zingg, A.W. Wind tunnel studies of the movement of sedimentary materials.  
1953 In: *Proc. Fifth Hydraulic Conference, Iowa Institute of Hydraulics Res. Bul. 34*, pp. 111-135, John Wiley, New York, N.Y.
- Zingg, A.W. and Woodruff, N.P. Calibration of a portable wind tunnel for  
1951 the simple determination of roughness and drag on field surfaces. *Agron. J.* 43:191-193.

ASSESSMENT OF LAND DEGRADATION IN AGRICULTURAL AND  
PASTORAL AREAS IN AUSTRALIA (1975-77)

by H.W. Pauli

1. INTRODUCTION

During 1975 to 1977 a nation-wide study of Australia's soil conservation problems was carried out collaboratively by the Commonwealth, the Territories and the States. The findings of the study will be published in 1977 in 14 reports. Report 13 "Land Degradation in Agricultural and Pastoral Areas" describes the methodology used in the assessment of land degradation in the agricultural and pastoral areas together with the results obtained from this assessment. This paper is based mainly on the description of the methodology contained in Report 13.

2. ORIGIN AND TERMS OF REFERENCE OF STUDY

The Study was started after the acceptance by State Premiers of the offer of funds by the Commonwealth Government for an interim program of assistance to the States during the financial years 1974/75 and 1975/76, to enable them to "step up their soil conservation activities ... in preparation for a long-term program". The main condition attached to the allocation of these funds was that the States co-operate with the Commonwealth Government in a study to establish a basis for a long-term national program of soil conservation in the context of an integrated approach to land management.

The five specified components of the Study were:

- (i) the development of a national approach to land resource survey and evaluation;
- (ii) the drawing up of a co-ordinated research program aimed at meeting the most urgent needs associated with soil conservation;
- (iii) study of legal, administrative, financial and land tenure systems associated with soil conservation and land management, including the matter of cost allocation and reimbursement in relation to works on private property;
- (iv) requirements for the recruitment and training of all categories of staff;
- (v) integration with other areas of government policy including rural reconstruction, water conservation and flood mitigation.

### 3. ORGANISATION AND DESIGN OF STUDY

A small central study team consisting of the Study Leader and Commonwealth officers, was established in the Bureau of Environmental Studies in Canberra <sup>1/</sup>. The Study Team resources were supplemented by State and Territory soil conservation officers working in Canberra at various times for periods of up to six weeks. The Study Team worked closely with the individual soil conservation authorities and with specialist Task Forces. In the former case, communication was maintained through a Liaison Officer in each soil conservation authority. Consultants were engaged for some parts of the Study.

To facilitate data collection the Study was divided into 10 main task areas:

1. Land Resource Survey and Evaluation
2. Land Degradation Assessment
3. Impact Analysis
4. Financing Arrangements
5. Conservation Programs
6. Research Programs
7. Legislation
8. Administration
9. Staff Recruitment and Training
10. Integration with related Government Policies and Programs

The land degradation assessment carried out in Task 2 was intended to not only provide a statement on the damage which has occurred, and is likely to occur, to land in Australia, but also to provide a general framework within which to consider solutions to soil conservation problems in terms of legislation, administration, policy, research, finance and staff.

### 4. SCOPE OF THE DEGRADATION ASSESSMENT

The State and Territory soil conservation authorities in Australia were established primarily for the mitigation, prevention and control of soil erosion in agricultural and pastoral areas. Their aim has been to foster land use and land management which improve the biotic productivity and stability of the land, and which at the same time minimise adverse local and transmitted effects of soil erosion.

Although the aim of the soil conservation authorities has not changed markedly, two significant developments have taken place in the scope of their work. First, increased attention is now given to forms of land degradation other than soil erosion, particularly the treatment of soil salinisation and rangeland degradation; and second, the authorities are being placed under increasing pressure to assist with the implementation of soil conservation measures on areas used for purposes other than agriculture and grazing, particularly the urban fringes, recreation areas and wherever site stability is disturbed by development.

---

<sup>1/</sup> Incorporated in the Studies Bureau on the establishment of the Department of Environment, Housing and Community Development, December 1975.

## Types of Land Use

Agriculture and grazing in the arid and non-arid zones were the only types of land use considered in detail in the assessment. Due to the shortage of quantitative information on existing land degradation caused by surface mining, recreation, forestry, urbanisation, transportation, communications and services, the land degradation associated with these forms of land use could not be inventoried in detail.

## Forms of Land Degradation

Over the years a number of causes of land degradation have been identified. A paper 1/, prepared by the Food and Agriculture Organisation (FAO) as a background document for the United Nations Conference on the Human Environment held in Stockholm in 1972, presented the following categorisation of forms of land degradation:

Category I - erosion and sedimentation, salts and alkali, organic waste, infectious organisms;

Category II - industrial organic wastes, pesticides, radioactivity and heavy metals;

Category III - fertilisers and detergents.

Despite the fact that the soil conservation authorities in Australia are primarily concerned with soil erosion and salinisation, the term 'land degradation' is preferred to the term 'soil degradation' in this report. Use of the former is more in line with current thinking on the misuse and disturbance of land, and takes into account the involvement of soil conservation authorities in an increasing number of the forms of land degradation listed in the FAO categorisation. Apart from this, the forms of Category I degradation in Australia are commonly linked with landscape processes, rather than with site processes.

The technical terms used in the Study are widely understood, but the following explanatory notes may be of assistance:

- Soil Erosion refers mainly to accelerated soil erosion, that is to soil erosion which results from man's use and management of land as distinct from 'geological' or 'natural' erosion which occurs irrespective of man's activities. The term Wind Erosion includes the erosion of coastal dunes used for grazing. Water Erosion in some instances includes landslips.
- Soil Salinisation or Soil Salting refers to soil salinity problems caused by man's use and management of land as distinct from the natural levels of salinity which occur in many Australian soils.
- Land Degradation means the deterioration in the stability or the potential biotic productivity of land resources currently used for agricultural and pastoral purposes, beyond that which might

---

1/ R.S. Rauschkolb : "Land Degradation", FAO Soils Bulletin No: 13 (1972)

occur in nature. It includes wind and water erosion and rangeland degradation as major forms, and soil salinisation or salting as a less widespread form, and one not necessarily associated with soil erosion but of economic and environmental importance.

## 5. SELECTION OF ASSESSMENT METHOD

### Previous Australia-wide Assessments

Several small scale maps were published in the 1940's and 1950's showing the distribution of wind and water erosion on cultivation and grazing land in Australia. These gave a subjective assessment of the severity of erosion, and being produced at a scale of approximately 1:30 000 000 provided only a general picture of the distribution of erosion-damaged land.

An abortive attempt was made in the mid-1950's to produce a Soil Erosion Map of Australia as one of the 1:6 000 000 map-sheets in the Atlas of Australian Resources.

The first attempt at quantifying the land degradation situation on a national scale was a study carried out by the Standing Committee on Soil Conservation <sup>1/</sup> in 1969 and 1970. The Committee's report <sup>2/</sup> included an assessment of the areas damaged by various classes of erosion in the non-arid zone of Australia and estimates of the cost of repairing the damage. The cost estimates were based on average treatment costs per hectare for each class of erosion damage in each State and Territory. Apart from the restriction of the Committee's study to the non-arid zone, the assessment had a number of weaknesses. For instance, the study provided estimates of the landholder installation costs but not the landholder maintenance costs of the structural measures required for the control of existing erosion. Also, it did not relate soil erosion to the major types of land use or show the distribution of erosion within each State and Territory.

### State and Territory Assessments

Soil conservation authorities in Australia carry out land degradation assessments as an on-going activity. The authorities in Western Australia, Victoria, New South Wales and Queensland have the responsibility for conducting soil erosion surveys and assessments conferred on them by their respective statutes.

The early degradation assessments, those carried out between the mid-1930's and the mid-1950's were, in general, aimed at:

- 
- <sup>1/</sup> The Standing Committee on Soil Conservation, established in 1946, is comprised of the heads of the State and Territory soil conservation organisations and representatives of the Commonwealth Departments of Primary Industry and Environment, Housing and Community Development. The Secretariat for the Committee is provided by the Commonwealth Department of Primary Industry, Canberra.
  - <sup>2/</sup> Standing Committee on Soil Conservation, "Study of Community Benefits of and Finance for Soil Conservation" (Australian Government Publishing Service, 1971).

- (i) examining the case for the establishment of soil conservation authorities in Australia;
- (ii) promoting interest in the adoption of soil conservation measures;
- (iii) establishing soil conservation priorities.

Some of the early assessments followed the establishment of State Erosion Committees, as recommended by the 5th Meeting of the Australian Agricultural Council in 1937. The most detailed and extensive assessment of erosion carried out in this early period was the survey by the Soil Conservation Service of New South Wales during the years 1941-1943 of erosion-damaged land in the whole of the Eastern and Central Divisions of New South Wales (480 000 km<sup>2</sup> or 60 per cent of the area of the State). Eight classes of erosion were delineated on maps at a scale of 2 miles to the inch. The survey was updated in 1967.

Since the mid-1950's degradation assessments have been conducted primarily for the planning and monitoring of soil conservation programs at district, regional and State levels. The main trends have been:

- (i) inclusion of land degradation assessments in land and water resource appraisal programs at regional and catchment levels, including catchment studies above existing or proposed water storages;
- (ii) integration of land degradation assessments with research and investigation projects, including the measurement of soil loss rates from major erosion events, studies of the distribution of degradation by social and economic groupings, and the development of computer techniques for the storage and manipulation of land resource and degradation survey data;
- (iii) recognition of secondary soil salinisation as a major cause of land degradation under dryland and irrigation conditions;
- (iv) adoption of the 'treatment measures' approach in assessments of degradation by soil erosion.

#### Selection of 'Treatment Measures' Approach

Land degradation assessments are usually carried out as degradation hazard or degradation damage assessments, the former being aimed at determining existing degradation. Degradation hazard assessments depend on a detailed understanding of the climatic, edaphic and vegetative factors leading to land degradation. Because these factors are not well understood on an Australia-wide basis and the development of the necessary understanding was beyond the resources of the Study, it was decided that some type of land degradation damage survey should be used. However, a general overview of degradation hazards was prepared as part of the Study.

Land degradation damage surveys usually inventory land damage in a qualitative way in terms of causal agent and type and severity of degradation. Such assessments have several limitations:

- . the terms used to classify degradation such as "severe water erosion", "minor wind erosion" are often subjective. Even when the terms are defined e.g. erosion in terms of depth of soil removed, their application in a field survey is very difficult and time consuming;
- . land treatment requirements and their costs cannot be deduced solely from an inventory of the damage. The complexity and cost of treatments are influenced by a variety of local considerations including the type of land use practised and social and economic factors. Hence, the validity of assigning an average treatment cost to land defined according to some qualitative scale, such as "severe water erosion", is, at best, questionable.

For these reasons it was decided to assess land degradation in terms of land treatment measures. This approach facilitates the integration of preventive and reclamation measures. It produces information relevant to local needs and directly quantifiable in terms of resource input requirements. This information can be brought readily to a dollar base for financial estimation or for the comparison of the costs of alternative treatment strategies.

The treatment measures approach is dependent on using experience gained in applying land degradation control treatments. Land damage surveys carried out in the 1930's and 1940's could not have made use of this approach because of the paucity of experience, at that time, in controlling soil erosion.

## 6. THE ASSESSMENT METHOD

### Arid and Non-Arid Zones

Australia was divided into an arid zone and a non-arid zone and each zone separately assessed.

The arid zone is defined as the area where the rainfall is too low or unreliable to support regular dryland cropping or the extensive establishment of sown pastures. This climatic zone boundary was selected for the following, largely technical reasons:

- (i) Types of land use and land management differ between the two zones.
- (ii) Land degradation forms and hazards, and soil conservation land treatment requirements differ between the zones.
- (iii) Legislative and administrative arrangements for preventing or controlling land degradation are often different for the two zones.

Regardless of the line chosen as the arid zone boundary, the transition from non-arid to arid conditions is, in reality, gradual and takes place over a wide belt of country. However, in 1974, an arid zone boundary was adopted by the Pastoral

Ecosystems Panel, a group set up by the Standing Committee on Agriculture, and this boundary, slightly altered to facilitate data compilation, was adopted for the assessment. The arid zone covers approximately 70 per cent of the continent.

### Objectives

The assessment, which was confined to lands under agricultural and pastoral use, was designed to provide the following information:

- (i) the nature, extent, location and severity of land degradation;
- (ii) the land treatment measures required in the short to medium term to maintain productivity and prevent such adverse transmitted effects of land degradation as excessive siltation and deterioration of water quality;
- (iii) the cost of installing and maintaining the measures in (ii);
- (iv) assessments of the urgency for controlling land degradation.

### Land Use

Land degradation is a function not only of factors of the natural environment but also of land use and land management. For a given natural environment, the type of land use and standard of land management determine the extent and rate of degradation. Form of degradation can also be strongly influenced by land use and land management.

Land in agricultural and pastoral use was allocated to the most appropriate of the following broad categories:

- |              |   |   |
|--------------|---|---|
| Agricultural | - | extensive cropping                                |
|              | - | intensive cropping, including irrigated cropping. |
| Pastoral     | - | arid zone grazing                                 |
|              | - | non-arid zone grazing.                            |

The term 'extensive cropping' refers to the production, under dryland conditions, of grains and other crops with similar cultural requirements. 'Intensive cropping' refers to the production of sugar-cane, vegetables, fruit (including grapes) and irrigated crops. Irrigated crops referred to in the Study were those grown in the large-scale irrigation areas drawing water from large aquifer or government - sponsored irrigation dams.

The term 'pastoral land use' includes all land in the arid zone used for grazing by cattle or sheep, and in the non-arid zone arable and non-arable land under native or improved pastures and used for grazing. In the assessment the land used in ley (crop-pasture) rotations was viewed as being under a cropping land use not grazing,



except where cropping occurs only at extended intervals and then principally in connection with a pasture improvement or regeneration program.

Approximately 65 per cent of the land area of Australia is used for agricultural and pastoral purposes. Slightly less than 2 per cent is used for crops; slightly more than 3.5 per cent is under sown pasture; and 0.2 per cent is irrigated. Commercial forests and forest reserves account for 5 per cent of Australia's land area.

Almost two-thirds of the arid zone is used for grazing. In recent years, approximately 20 per cent of both the sheep and the cattle in Australia have been grazed in the arid zone, the sheep being predominantly in the southern winter rainfall area and the cattle predominantly in the hotter, northern summer rainfall area.

The grazing industries in the non-arid zone operate in a diversity of environments, ranging from winter to summer rainfall regimes, and from tablelands with high rainfall and cold winters to the coast and tropics with high rainfall and mild winters.

These broad categories of land use were selected for the following main reasons:

- (i) Degradation problems often differ markedly between the categories. For instance, soil salinisation occurring under dryland cropping is different in many respects from that occurring under irrigated cropping.
- (ii) Agronomic, mechanisation and other requirements for successful crop and animal production differ markedly between the categories and many of these have to be taken into account in soil conservation planning. For instance, internal soil drainage is an important factor in the production of some horticultural crops and can determine the gradient and length of contour banks used with these crops. Irrigation often requires the adoption of special parallel soil conservation layouts.
- (iii) Levels of soil conservation inputs required for satisfactory land degradation prevention and control vary with the land use categories. These inputs include technical assistance such as planning and surveying as well as investments in soil conservation works such as contour banks and waterways, fertilisers, fencing and machinery. For instance, concrete waterways may be justified in a horticultural area but not in a cereal growing area.
- (iv) The categorisation facilitates the identification of the degradation problems facing the major sectors of rural industry.

#### Assessment Technique

The assessment was carried out by two task forces <sup>1/</sup>, one for the arid zone

---

<sup>1/</sup> Within each State and Territory the task forces were assisted by soil conservation and other officers with regional and district experience of land degradation problems.

and the other for the non-arid zone. Despite differences in detail in the procedures adopted, the same general principles were followed for both zones. Both task forces carried out their assessments to obtain the four types of information previously listed as objectives in the following four-stage sequence:

- (i) delineation and description of land zones and "types of country" and description of the land degradation problems within them;
- (ii) determination of treatment measures required to control the described degradation;
- (iii) costing of the treatment measures in (ii);
- (iv) rating of the urgency of applying the treatment measures in (ii).

In addition, an attempt was made to assess the land degradation treatment requirements which could be expected to result from likely future land use changes caused by socio-economic forces.

Delineation and Description of Land Zones and Regions,  
"Types of Country", and Degradation Problems

For the purpose of the assessment Australia was divided into 95 areas: 77 'land zones' in the non-arid zone and 22 'regions' in the arid zone.

The non-arid 'land zones' were selected on the bases of natural environmental features and recognisable associations of land degradation. However, for convenience, the actual boundaries were in many cases adjusted to coincide with statistical or administrative boundaries.

Most of the boundaries of the arid zone regions are statistical or administrative area boundaries, except in Western Australia where environmental factors dictated the subdivision pattern.

'Land zones' were described in terms of:

- (i) relevant environmental features;
- (ii) land degradation problems, including causes and effects;
- (iii) land use and where convenient, land tenure;
- (iv) statistical areas, local authority areas, numbers of rural landholders.

A proforma was used for compiling this information.

The size of the land zones ranged from 1 150 km<sup>2</sup> to 351 800 km<sup>2</sup>, depending on the diversity of the physical environment and the intensity of land use. The number of landholders in the land zones ranged from 2 to 19 000. The size of the arid zone region ranged from 70 000 km<sup>2</sup> to 890 000 km<sup>2</sup>; the number of landholders in the regions ranged from 28 to 1 179.

A proforma was used for compiling data on the area of each non-arid 'land zone' and arid region, and the number of landholders and areas of the broad types of agricultural and pastoral land use in each of them.

Land degradation treatment requirements vary widely between sites in the arid zone. In recognition of this, 15 'types of country' considered characteristic of the arid zone were identified, delineated, and described in terms of their terrain, soils, and vegetation. Assessments were made for each 'type of country', but on a regional basis to determine the regional situations and requirements. Five degrees of severity of degradation were adopted for the arid zone. These are described in Appendix A. The assessment for each region involved estimating the area suffering each degree of severity of degradation for each 'type of country'.

### Treatment Measures

The objective of soil conservation treatment measures is to reduce or neutralise the impact of the causal agents of land degradation. Adoption of land management measures and land use consistent with this treatment objective is fundamental to the long term prevention and control of land degradation. However, in the many cases where land damage has already reached an advanced stage, improved standards of land use and land management may not, by themselves, be sufficient to rehabilitate the land surface. In such cases, special works, such as structural erosion control measures or land drainage works, are also necessary. Where land continues to degrade despite the adoption of conservation land management measures and erosion control measures, both the form and intensity of the land use must be called in question.

Given this approach to the treatment of rural land degradation problems, treatment measures logically fall into the four broad groups described below, which were adopted for the assessment of the extent, type, and costs of the land degradation treatment requirements:

#### . Land Management Practices (LMP)

Land management strategies, including contour ploughing and other cultivation practices and grazing management practices.

Practices are nearly always required, whether other measures are necessary for land degradation prevention and control, or not.

#### . Land Management Works (LMW)

Capital items such as broad-acre structural works, e.g., earthen banks and waterways, and fencing and waters for stock control.

Land management works are necessary in areas where land management practices alone are insufficient to prevent land degradation at the proposed intensity of land use.

## Erosion Control Works (ECW)

Capital works to control existing land degradation, including concrete structures and special vegetative measures.

Erosion control works are required where land management works supported by land management practices will not control the existing, active land degradation. These works are costly. Normally they are only installed to prevent damage to land or land improvements away from the degraded site, or to stabilise a landscape so that adjacent lands may be safely used given the appropriate land management practices and land management works.

## • Land Use Change (LUC)

Necessary changes in present land use for sites where a high degradation hazard would persist, even with the application of land management practices, land management works and erosion control works.

Classification of treatment measures into these four groups, that is, their allocation to LMP, LMW, ECW and LUC, provides a breakdown of conservation activities in a form convenient for discussion of the division of responsibility, as between the landholder and the larger community, for the implementation of the various treatment measures required in a soil conservation scheme. For instance:

- It can be argued that landholders should, in most cases, bear the full cost of land management practices (LMP's) which are, or should form part of standard farm management.
- Where works produce both on-site and off-site benefits, i.e., reduce the adverse external effects of land degradation, there may be a case for the community to meet a portion of the treatment costs. Land Management Works (LMW's) are essentially preventive in nature, in that their purpose is to prevent land degradation occurring under present or proposed land use. It could therefore be argued that most LMW's should be viewed as a development and operational cost which should be substantially borne by the landholder.
- The treatment measures applied to severe, existing land degradation (ECW's) typically provide few direct or significant economic benefits for the present landholder and often can only be justified in terms of the external benefits brought to the neighbourhood or nation. For example, eroding gullies may provide rapid transit for large quantities of sediment into main drainage systems in important catchments, but their control, while desirable from the viewpoint of watershed management, may involve landholders in increased costs without compensating increases in gross returns. In such instances, and particularly where land degradation predates the passage of soil conservation legislation, or has been initiated by off-farm degradation - as may occur through the advance of gullies across property boundaries - a case may exist for some form of cost sharing.

Situations calling for LUC solutions can arise in a variety of ways, including some in which the landholder clearly has been directly responsible for land mismanagement, and others in which the requirement for change arises for reasons outside the landholders control, as for instance where water supply catchments are proclaimed. With LUC's, the fair allocation of costs as between the landholder and the larger community can only be assessed on a case by case basis.

Six combinations of the groups of treatment measures were used in the assessment:

LMP;  
LMP + LMW;  
LMP + LMW + ECW;  
ECW;  
LMP + ECW; and  
LUC.

These combinations were designated as treatment categories and are further described in Appendix B. A conceptual approach to the application of practices and works to cropping land is shown in Appendix C and to grazing land in Appendix D.

The six combinations require different advisory and technical inputs by the soil conservation authorities. Treatment Category 1 (LMP) requires mainly an extension effort to promote the application of existing knowledge of land management practices. There are however, some land management practices, such as those related to the surface management of soils used for grain growing in Queensland and northern New South Wales, where current recommendations will remain tentative until additional research has been conducted. Treatment Categories 2 (LMP + LMW) and 3 (LMP + LMW + ECW) make the heaviest demands on the services of soil conservation authorities because the application of the measures includes both an extension effort and a considerable amount of time spent on resource inventory, land use planning, and plan implementation. Treatment Categories 4 (ECW) and 5 (LMP + ECW) usually require lower planning and implementation inputs.

Nine measures were identified as the main treatment measures required in the arid zone. These are described in Appendix E. For comparison between information on the arid and non-arid zones in the assessment, the nine treatment measures were classified into the LMP, LMW, ECW, and LUC groupings (See Appendix E).

The non-arid zone assessment included the estimation of the total area of land currently in each major type of agricultural and pastoral use requiring each category of treatment. Where possible, those areas which have already been partially or fully treated were also estimated.

### Costing

Treatment costs were estimated in four categories:

- (i) installation or establishment of land management practices (LMP);

- (ii) installation of works, both land management works (LMW) and erosion control works (ECW);
- (iii) maintenance of LMW and ECW; and
- (iv) land use changes (LUC).

Average contract rates and retail sale prices at 30 June 1975 were used for estimating costs in categories (i), (ii) and (iii). Estimates by local soil conservation specialists of the reduction in the market value of land following a change to a less damaging form of land use were used for determining costs in category (iv).

It was considered reasonable to use contract rates as a basis for cost estimating because:

- . contractors already install many of the land management works and erosion control works;
- . even when landholders use their own equipment (in many cases specially purchased for soil conservation purposes) the cost of owning and operating this equipment approximates average contract rates when allowance is made for the time spent by the landholder in carrying out the works;
- . landholders nearly always assist soil conservation officers in laying out soil conservation works. Landholder's time in performing this task is not included in the cost estimates for installation of works;
- . although many landholders build structural works with their own equipment, experience has shown that structures built by experienced contractors are likely, in many localities, to better withstand highly erosive rainfall events;
- . landholders may lose income if they break their normal farm routine to instal soil conservation works themselves;
- . subsidy rates paid under many of the soil conservation subsidy schemes operating in Australia are based on contract rates.

Costs in categories (i), (ii) and (iii) are borne entirely by individual landholders and other land users responsible for the management of land (e.g. local authorities) except where the measures are subsidised directly through grants or indirectly through taxation concessions. The costs of changes in land use, category (iv), are normally borne by the landholder, except where resumption or a change in land use is enforced by law, in which case the landholder may have a claim for compensation. Government services to assist landusers in the prevention or control of degradation are provided at public expense, except in the few instances where landholders are charged for government technical services. Estimates of these costs are not given in this paper.

Maintenance costs of works were estimated only in the non-arid zone because lack of experience in most States and Territories precluded their estimation for the arid zone. Many land management practices were not costed because of the absence of reliable data. In the non-arid zone it was possible to estimate the installation and maintenance costs of only three of the eleven land management practices recommended in Appendix C for various types of cropping land, and of only three of the nine recommended in Appendix D for grazing land.

Treatment measures applied in the non-arid zone prior to June 1975 were valued at average contract rates and retail sale prices operating at June 1975. Subtraction of these values from the total costs of treatment gave the cost of applying the treatments still needed. Maintenance costs were estimated for the total treatments required i.e. treatments applied prior to June 1975 and treatments to be applied after June 1975.

### Urgency

A three level system for rating the urgency with which treatment measures might be implemented was applied to each category of treatment in each 'land zone' or 'type of country'. The rating system, which was applied in both the arid and non-arid zones was as follows:

- (i) irreversible damage to the land resource or serious off-site effects if no action taken to control degradation;
- (ii) necessary to take action to avoid further loss of productivity potential or to avoid undesirable off-site effects;
- (iii) degraded situation but presenting no immediate increased hazard.

Two proformas, one for the arid zone and one for the non-arid zone, were used for recording the above information on areas, costs and urgency of the treatment measures required to control existing degradation under current land use.

APPENDIX A

DEGRADATION CLASSIFICATION USED IN ARID ZONE ASSESSMENT

DEGRADATION CLASS CODE	DEGRADATION CLASS DESCRIPTION
0	No degradation
1	Vegetation degraded but little erosion
2	Small scalds and/or rills of thin sheeting ( < 10% of area affected)
3	Large scalds and hummocking with or without thin sheeting or gullies on lower slopes (10-50% of area affected)
4	Large scalds and/or surface deflation, and/or extensive sheeting, terracing or gullying ( > 50% of area affected)



APPENDIX B

TREATMENT CATEGORIES CLASSIFICATION

TREATMENT CATEGORY	DEFINITION		EXAMPLES
0	Land requiring no special treatment under existing land use		"Prime" grazing or cropping land.
1	Land requiring land management practices	LMP	Less hazardous, sloping cropping country requiring stubble mulching. Strategic grazing of hill country. Chisel seeding.
2	Land requiring land management practices and works	LMP LMW	Cropping land requiring contour cultivation, stubble mulching, contour banks.
3	Land requiring erosion control works and land management works and practices	LMP LMW ECW	Eroded cropping country requiring contour cultivation, stubble mulching, contour banks, waterways, gully battering.
4	Land requiring erosion control works only	ECW	Gullying of stream systems in grazing land. Unstable sand dunes requiring establishment of vegetation
5	Land requiring erosion control works and land management practices	ECW LMP	Gullied, tunnelled, sheet eroded grazing land.
6	Land requiring change to less hazardous type of land use	LUC with or without LMP, LMW, ECW	Cropping land that should revert to grazing or forestry. Deteriorated grazing land to be excluded from use.

LMP (Land Management Practices) - Cultivation or grazing management practices  
e.g. pasture improvement, strategic grazing, temporary destocking, contour cultivation, stubble mulching, broader rotation, subdivisinal fencing.

LMW (Land Management Works) - Broad-acre structural works required to prevent degradation  
e.g. contour banks, waterways, stockwater dam.

ECW (Erosion Control Works) - Works to control existing erosion  
e.g. concrete or rock structures, gully battering, fencing for erosion control, tree planting for erosion control.

LUC (Land Use Change)  
e.g. changes in present land use where a high degradation hazard would persist.

## APPENDIX C

### TREATMENT MEASURES ON CROPPING LAND

The treatment measures required on cropping land can be grouped according to three principles: soil selection, soil management and water management.

#### Soil Selection

Each soil type has an optimum management requirement. The purposes of soil selection are:

- a) to allow different soil types to be treated according to their specific needs;
- b) to avoid, as far as possible, the incorporation of widely different soil types into an area to be cropped according to uniform management, as this may render some proportion of the land liable to degradation because it receives less than optimum treatment.

#### Soil Management

Soil management has two objectives:

- a) to retain soil cover to avoid the destructive action of rain-drop impact and splash and wind blast and to reduce the velocity of overland flow;
- b) to achieve a soil condition that provides an optimum growing medium through its retention of qualities of structure, stability, aeration, moisture and fertility.

#### Water Management

The purposes of water management are:

- a) to conserve water in the soil at a level optimal for plant growth;
- b) dispose safely of excess water.

A list of recommended treatments for cropping land, based on the above principles, is shown in Table 1. Many of the treatments listed interact to give an enhanced result. The best mix of treatments varies according to locality. Cropping areas prone to wind erosion have not been mentioned separately in the list. They depend for their stability solely on land management practices.

Table 1  
(Appendix C)

TREATMENT MEASURES FOR LAND DEGRADATION IN CROPPING AREAS

PRINCIPLE OF LAND TREATMENT	TREATMENT MEASURE	TREATMENT GROUPING
Soil Selection —————  Soil Management ———— Soil Cover Soil Condition ————  Water Management ———— Retention ————— Disposal —————	Selective land management according to soil type  Cover crop Shorter fallow period Optimum planting time Adequate fertilization Crop residue incorporation Improved tillage practices Soil amendments Improved rotations Strip cropping Contour cultivation	Land Management Practices (LMP)
	Graded contour banks Grassed waterways	Land Management Works (LMW)
	Gully stabilization	Erosion Control Works (ECW)

## APPENDIX D

### TREATMENT MEASURES ON GRAZING LAND

The treatment measures required on grazing land, although covering a broad range of situations, can be grouped according to three principles: grazing selection, grazing management, and water management.

#### Grazing Selection

Different pasture species or associations of pasture species vary in the type of grazing management which they require. The purpose of grazing selection is to avoid, as far as possible, the incorporation into one paddock of those types of grazing requiring different management practices.

#### Grazing Management

The main objectives of grazing management are:

- a) to maintain a pasture condition that will give a sustained yield from a pasture of the desired composition;
- b) to maintain a pasture cover to avoid the destructive action of water or wind.

#### Water Management

The purposes of water management are:

- a) to conserve water in the soil at a level optimal for plant growth;
- b) to dispose safely of excess water.

A list of the recommended treatments based on these principles is shown in Table 2. The selection and best mix of treatments varies according to locality.

Table 2  
(Appendix D)

TREATMENT MEASURES FOR LAND DEGRADATION IN GRAZING AREAS

PRINCIPLE OF LAND TREATMENT	TREATMENT MEASURES	TREATMENT GROUPING
Grazing Selection  Grazing Management <ul style="list-style-type: none"> <li>Pasture Composition</li> <li>Pasture Cover</li> </ul>	Selective grazing management Strategic fencing  Pasture species selection Adequate fertilization Strategic burning  Stock type selection Grazing intensity Grazing rotation Stock water distribution	Land Management Practices (LMP)
Water Management <ul style="list-style-type: none"> <li>Retention</li> </ul>	Contour ripping Pasture furrowing Water spreading	Land Management Works (LMW)
Disposal	Diversion banks Gully stabilization	Erosion Control Works (ECW)

APPENDIX E

TREATMENT MEASURES IN ARID ZONE

TREATMENT MEASURE CODE	TREATMENT MEASURES (AND GROUPINGS)
1	Destock (LUC)
2	Reduced stocking (IMP) and some fencing (LMW)
3	More watering points (LMW)
4	Mechanical treatment: pitting, furrowing, chisel ploughing (ECW)
5	Water spreading (ECW)
6	Water ponding (ECW)
7	Large structure (LMW)
8	Reseeding fertilizer (seed coat) (ECW)
9	Pasture management (IMP)