GLOBAL SOIL CHANGE

Report of an

International Institute for Applied System Analysis,
International Society of Soil Science,
United Nations Environmental Programme

Task Force on the Role of Soil in Global Change

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FOREWORD

The International Institute for Applied Systems, is a non-governmental, interdisciplinary research organization founded in 1972. Among its most relevant objectives are "the initiation and support of individual and collaborative research on problems associated with environmental change, and thereby to assist scientific communities throughout the world in tackling such problems". One means to this goal is by direct support of ICSU's International Geosphere-Biosphere Programme, UNEP's International Panel on Climate Change, and similar organizations.

IIASA's sixteen national member organizations, located in eastern and western Europe, Asia and North America, are scientific and professional bodies, rather than political ones. The Institute is particularly suitable for bringing together the appropriate personnel to solve scientific research problems involving east und west. It does so through the formation of programs of study, presently aimed at enhancing methods of mathematical analysis /System Decision Support Program/ and at studying change in global population /Population Program/, technology /Technology, Economy and Society Program/, and environment /Environment Program/.

The present environmental change activities at IIASA are centred on the Environment Program. The program includes a group of 25 research scholars working on three designated projects. The projects concentrate on management of large international rives /International Water Resources Project/, modelling of European acid rain distributions /Transboundary Air Pollution Project/, and ecologically sustainable development of the biosphere /Biosphere Dynamics Project/. It is notable that each of the projects were developed independently of the other, but that each of these projects is aimed directly or indirectly at development and use of mathematical models of environmental phenomena. The models are designed specifically to be interrogated in order to reveal the options available to political decision-makers on specific environmental issues. Thus, the main goals of each project also are derived directly from specific issues of interest, rather than from e.g. a fundamental curiosity of how the environment functions.

Global change issues which define both the nature of the Biosphere Project modelling aims, have a number of soil modelling requirements. Both spatial and temporal scales of the soils information are needed. The present report gives some of the concepts underlying such soils information.

A. M. SOLOMON

Biosphere Dynamics Project
IIASA, Vienna

PREFACE

The present report is one of a series of documents by soil scientists in preparation of a coordinated input by the various national and international centres on soil research and management into the International Geosphere-Biosphere Programme /IGBP or "Global Change" Programme/ initiated by the International Council of Scientific Unions /ICSU/. They are, in chronological order:

- Two international task force meetings on "Concept of Global Soil Change", taken place between 24-25 April 1989 and 15-17 December 1989 in Budapest /Hungary/ and Moscow /USSR/, respectively; organized by IIASA, Vienna.

Proceedings, edited by R. W. ARNOLD, I. SZABOLCS and V. TARGULIAN, published by IIASA /this report/.

- An international conference on "Soils and the Greenhouse Effect"; the present status and future trends concerning the effect of soils and their cover on the fluxes of greenhouse gases, the surface energy balance and the water balance, taken place between 14-18 August 1989 in Wageningen, the Netherlands; organized by the International Soil Reference and Information Centre /ISRIC/.

Proceedings, edited by A.F. BOUWMAN, under the title "Soils and the Greenhouse Effect", published by John Wiley and Sons, Chichester UK, early 1990.

- An international workshop on "Effects of Climatic Change on Soil Processes in the Tropics and Subtropics", to take place between 12-14 February 1990 in Nairobi, Kenya; organized by the International Society of Soil Science /ISSS/ and the United Nations Environment Programme /UNEP/.

Proceedings, edited by H.P. SCHARPENSEEL and M. SCHOEMAKER, to be published in mid 1990 by Elsevier Science Publishers, Amsterdam, the Netherlands.

- A symposium on "Global Soil Changes and their Dynamics in a Changing Environment" in the framework of the 14th International Congress of Soil Science, 12-18 August 1990 in Kyoto, Japan.

Proceedings of the symposium to be edited by H.P. SCHARPENSEEL and to be published by the Japanese Society of Soil Science in association with ISSS.

The four activities were promoted by the ISSS standing Committee on International Programmes /CIP/ and were financially supported by UNEP.

It is the intention of ISSS to prepare, on the basis of all above proceedings, a separate Executive Summary on the Role of Soils in Climatic Change, to be submitted to the Scientific Advisory Council of IGBP and to appropriate international fora, including the UN specialized Agencies concerned.

W.G. SOMBROEK
Secretary-General of ISSS,
Wageningen

EDITORIAL PREFACE

By an agreement between IIASA and the Hungarian Committee for Applied Systems Analysis, a Task Force Meeting on the Concept of Global Soil Change took place in Budapest from 24 to 27 April, 1989. The participants agreed on the preparation of a publication on Global Soil Change addressed to the world community of scientists involved in IGBP, e.g. ecologists, climatologists, hydrologists, biologists, etc. as well as decision- and policy makers of high level, who need to elaborate the holistic and comprehensive concept of global soil change as a part of the general concept of global geosphere-biosphere change.

The main stimuli for the preparation of such publication were:

a. the extreme necessity of the global and holistic spheric approach to world soils and soil patterns, that is, to land pedosphere and to all interactions of the pedosphere with the other natural spheres and with all kinds of human activity and human life;

b. the peculiarity of the pedosphere as an independent genetical, structural and functional subsystem within the biosphere-geosphere with its own laws of evolution, distribution and functioning;

c. the international and interdisciplinary aspiration to understand the essence and spatial-temporal distribution of the major mechanisms of pedospheric changes due to both natural and anthropogenic factors and forces;

d. the desire to understand the major consequences and results of pedospheric changes on other components of nature and society /feedback from pedosphere to biosphere-geosphere-society systems/;

e. and last but not least: the feeling of resentment for the lack of scientific recognition that pedology is such an interesting, attractive, exciting and profound science, and for such an important and polyfunctional natural body as soil and the world's pedosphere.

The publication should be scientifically sound and based on facts, but it is intended to be easily read and clearly understood by both specialists and laymen. The book, based on an analysis of the existing knowledge of the past, present and future of soils of the world, besides the description of processes and situations, should also include some predictions and recommendations.

After long discussions the scheme of the chapters of the "best-seller" was accepted and the members of the task force took the responsibility to serve as coordinators and contributors of the respective chapters.

It was also agreed that the book should be available at the 14th Congress of the International Society of Soil Science to be held in Kyoto, Japan in August, 1990, and besides the interested soil scientists an ample number of copies should be submitted to interested international organizations as well as to the competent agencies and projects /e.g. IGBP, UNEP, MAB or federal agencies/.

The second Task Force Meeting on the Concept of Global Soil Change was held in Moscow between 15 and 17 December, 1989 and was supported by UNEP and hosted by the Centre for International Projects of the USSR State Committee for Environmental Protection. At this meeting the chapters of the publication were presented and discussed and a final decision was made on the context of the book as well as on the coordinators and contributors.

R. W. ARNOLD, I. SZABOLCS and V. O. TARGULIAN were appointed as editors of the publication.

The coordinators and contributors of the different chapters are as follows:

	CHAPTER	COORDINATOR	CONTRIBUTOR/S/
I	Introduction	V. O. TARGULIAN	R. W. Arnold, A. M. Solomon, I. Szabolcs
II	Pedosphere	V. O. TARGULIAN	R. W. Arnold, B. G. Rozanov
III	Soil cover of the World	R. J. DUDAL	N. A. Karavaeva, V. O. Targulian
IV	Types of soil processes and changes	G. VÁRALLYAY	H. W. Scharpenseel, V. O. Targulian
V	Paleosols in the context of environmental changes	D. H. YAALON	H. W. Scharpenseel, W. G. Sombroek
VI	Anthropogenic effects on soils	I. SZABOLCS	J. Hrasko, B. G. Rozanov, H. W. Scharpenseel, V. O. Targulian
VII	Future changes of the pedosphere	R. W. ARNOLD	W. G. Sombroek, I. Szabolcs, V. O. Targulian
VIII	Spatial soil databases and modeling	M. F. BAUMGARDNER	
IX	Conclusions and recommendations	R. J. DUDAL	G. W. Scharpenseel

The editors of this publication wish to express their gratitude to all coordinators and contributors of chapters for their help and understanding, which made it possible to finalize the publication in a comparatively short time.

The intention of the task force was to give an overall picture on global soil change based on a uniform use and common technical understanding. Still, due to the large number of authors, various opinions and scientific approaches of some questions can possibly be found in different places of the book. Evidently, the various parts of the publication are in their author's credit. The editors had to respect the authors' opinions as long as these did not result any misunderstandings or confusion in the interpretation of the text. Consequently, the editors made no changes in the manuscripts with the exception of inevitable, minor corrections necessary for a uniform structure.

According to the decision of the Moscow Meeting, to eliminate the repetitions, an integrated List of Selected References was compiled and published from the list of references submitted by the coordinator of each chapter.

We must acknowledge the assistance and contribution of many persons. A large number of colleagues took part in the preparation of each chapter, besides the coordinators and contributors. Prof. M. BAUMGARDNER, coordinator of Chapter VIII, wishes to extend appreciation to Dr. Norberto FERNANDEZ, Purdue University, USA for his valuable contribution to his chapter. The undersigned wishes to express his appreciation to Dr. M. RÉDLY, who offered her assistance in the final stage of the editorial process.

We wish to acknowledge the help and support of the International Institute for Applied Systems Analysis /IIASA/ and especially of Prof. Dr. B. R. DÖÖS, Leader of the Environmental Programme, and Dr. Allen M. SOLOMON, Leader of the Biosphere Project in the preparation and realization of this publication.

Gratitude should be expressed to the United Nations Environmental Programme, and particularly to Dr. S. A. EVTEEV, Assistant Executive Director and Dr. A. AYOUB, Senior Programme Officer of Terrestrial Ecosystems Branch, for their support and financial assistance.

The President of the International Society of Soil Science, Prof. Dr. A. TANAKA, the Vice-President, Prof. Dr. Y. TAKAI, and Secretary General, Dr. W. G. SOMBROEK, offered their invaluable help during the entire process of preparing and editing the book, for which the editors express their sincere thanks.

We are deeply indepted to Dr. T. ASBOTH, Secretary and Ms. Zs. ZÁMORI from the Hungarian National Member Organization of IIASA, who supported and assisted the activity of the Task Force from the very beginning.

Appreciation should also be extended toward the USSR Centre of International Projects, and particularly to Dr. T. A. SAIKO, Deputy Co-ordinator of Desertification Control Projects, for hosting the Moscow Meeting.

The loyal assistance of Dr. M. TOLNAI, Director and Ms. I. DOBI-NAGY, Business Executive of the Institute for Research Organization of the Hungarian Academy of Sciences /Budapest/ in the realization and printing of this book should be acknowledged.

Last but not least, the editors are deeply indebted to the clerical staff, which was engaged in technical editing, in preparing translations, drawings, typing, etc. and supplied long hours of work in the preparation of this book: Ms. I. HETEI, Ms. I. KEMENES, Ms. S. KOVÁCS, Ms. V. LACZKÓ, Mr. Z. SZILVÁSSY, Ms. K. TEPLÁN, and Ms. I. VÉGH. Sincere thanks should be expressed also to Ms. Marylin BRANDL, Secretary, Environmental Programme /IIASA/, who willingly cooperated with the members of the Hungarian group throughout the whole time.

Budapest, February, 1990

I. SZABOLCS

Chapter I

INTRODUCTION

Theoretical and practical necessity of studying global soil change

Landscapes developed long before the appearance of man. Mankind has been altering the earth's environment for at least two million years. During most of this time man's influence has been minor and local. He has had both positive and negative effects on the environment. But recently his impact has increased on a global scale, embracing all regions and all components of the environment. We are now faced with many global issues as a result of anthropogenic changes of the whole biosphere-geosphere system, each of its components, and their linkages and feedbacks.

Today the situation is characterized by:

1. Increasing interest in assessments of global changes of this very complicated system.
2. Many kinds of human activity on land and ocean have led to the deterioration, degradation and even complete destruction of the natural systems and/or their separate components.
3. Realization that man has significantly improved the environment to provide the necessities of life and the growth of civilization.
4. Man's ability to change the natural environment is creating uncertainty of our understanding and comprehension of the earth as a system.

There is a need to study the complicated interactions of nature and the interactions between nature and society in order to adapt, or mitigate various natural and man-made changes within the biosphere-geosphere-society system.

The system has developed and functions by the simultaneous presence on the earth's surface of the atmosphere, hydrosphere, lithosphere, biota and human activity. "Secondary" spheres of interaction of these components also exist. Within such spheres of interaction all the phases and fluxes of substances /gaseous, liquid and solid, organic and inorganic, biotic and abiotic, natural and anthropogenic/ intersect, mix and interact.

Important interactions occur in the three major biotic-abiotic spheres: pedosphere /soil cover/, and the photic and bentic zones of the ocean. These spheres support the biota and serve as the source of nutrients for the functioning and for production of the biomass.

In Fig. 1 a schematic model on the above described functions of the pedosphere and of its interaction with other systems is demonstrated.

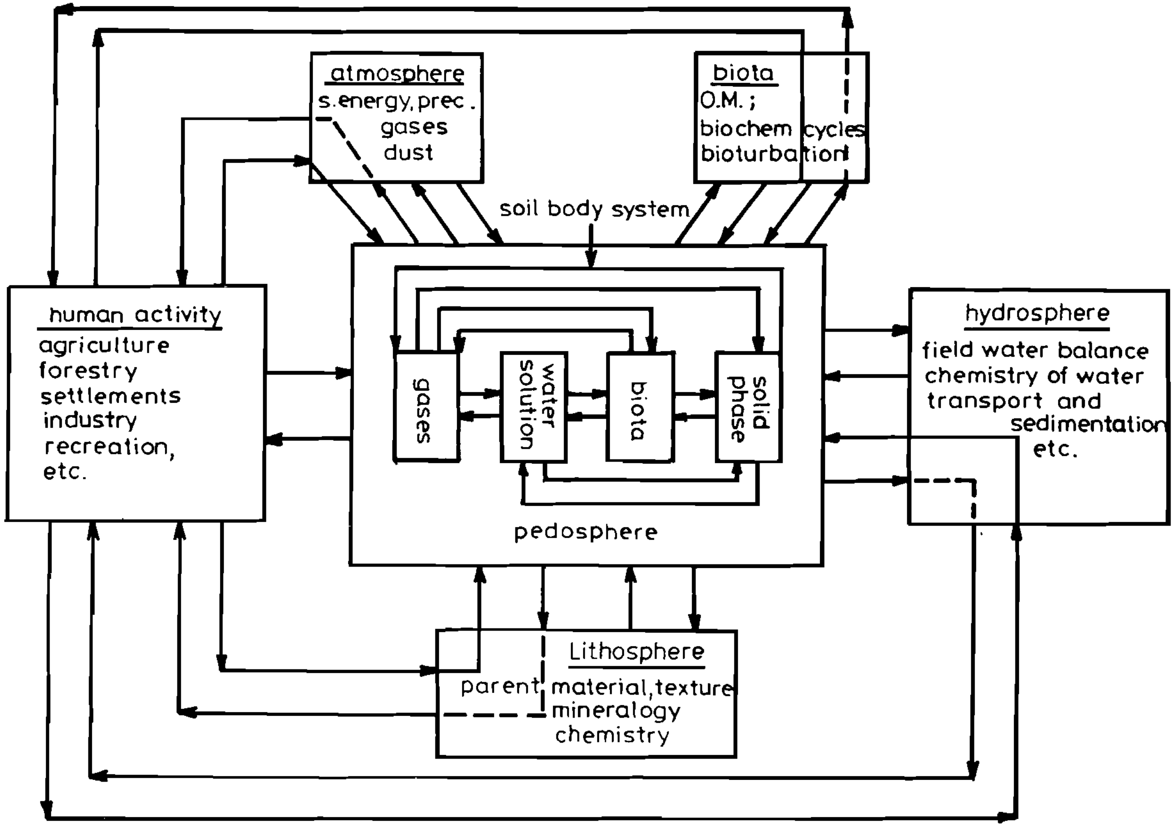

Figure 1. Model of the natural and human-induced interactions within the soil; and between soil and other bio-geospheric subsystems

The pedosphere is the important natural resource for growing food, feed, timber and fiber. In addition to the physical support of life the pedosphere has many other important functions, such as atmospheric, hydrospheric, lithospheric. Soils function not only as a water-nutrient-life media but also as redistributors and regulators of most of the important fluxes of matter and energy.

Due to the very complex /horizontal and vertical/ heterogeneity of the pedosphere and to the high variability of soil age and duration of soil forming processes, all soil functions and properties vary both in space and time. Knowledge of the main linkages and feedbacks between the pedosphere and other natural and man-made systems is important to understand and formulate the concept of global soil change.

Soils change because of their ever-intensifying use. The changes may be gradual, rapid, or even catastrophic. Such changes in the pedosphere affect the immediate carrying capacity of the land, through their influence on the vegetation and land-use types, run-off, evaporation, groundwater quality, and so forth. Directly or indirectly the soil changes have a substantial effect on global climatic conditions, which in turn, influence soils.

It is important to study the pedosphere conceptually as well as practically. On one hand studies should analyze past, current and future changes of the pedosphere influenced by the other changing sphere, including different types of human activities; on the other hand the influence of a changing pedosphere on other spheres and on human life should be quantified and evaluated.

"Concepts of Global Soil Change" attempts to focus the attention of those who study the biosphere-geosphere on the global aspects of the pedosphere and on the importance of describing and understanding changes of the pedosphere for the functioning of the whole earth system and the required human responses.

This publication reflects a concern about global soil changes by considering the following questions:

- What is the place and the role of the pedosphere within the biosphere-geosphere system?
- What are the main functions of the pedosphere?
- What is global soil change?
- What are the main factors and trends of pedosphere changes?
- What is the feedback from a changing pedosphere?
- .What are relevant approaches to the study of those changes?
- What important gaps exist in our knowledge about the qualitative and quantitative characterization of the structure and functioning of the pedosphere?
- What databases are relevant for studying global soil changes?
- What recommendations can be offered to help describe and understand global soil change?

IIASA's interest in environmental change

Global carbon cycle issues

The basic problem is to understand the role of the terrestrial biosphere in the global carbon cycle. There are three primary sources of the large uncertainty:

a. inadequate estimates of the biomass amounts and variations characteristic of various biotic communities and their soils,
b. inability to precisely measure historic and present changes in land use and deforestation, and
c. poorly understood transients in carbon dynamics of biotic communities /decay and recovery rates/.

The current uncertainties in estimates of biomass amounts and variations follow from too few field samples.

Additionally, measurements of below ground biomass will require large expenditures of manpower on field studies, many of them at the spatial scale of meters to kilometers. The below ground processes form perhaps the uncertainty of greatest potential effect on terrestrial carbon cycling.

The rate of deforestation includes uncertainties in estimates of the total clearance rate, of permanent versus temporary clearing, of primary versus secondary or fallow forests, and of current and historical land use. Deforestation and afforestation are intimately linked to soil features, especially to erosion and changing soil fertility. The documentation of current land use, and the prediction of future land use are critical components in estimating future carbon storage characteristics of the globe. In that regard, soil properties provide the most important local limit, particularly to the amount and kind of agriculture which can take place under climate characteristics.

Poorly understood transients in carbon dynamics will probably only be described accurately when mechanistic models can provide a spatially and temporally-detailed accounting of both the loss and recovery of carbon storage which is measurable in the field.

The transients in vegetation follow from competition among individuals. Therefore, no matter what aggregated variables may be required /e.g. biogeochemical cycling phenomena, standing crop biomass, etc./, models themselves must encompass processes measured for areas of no more than about one square kilometer at which competition for light, water, and nutrients occurs among the largest plants, i.e. trees.

The replacement of trees by new, better adapted species is a major point of uncertainty. One critical question involves rate of climate change, not the eventual magnitude of climate change.

Soil information, combined with general principles of plant growth and ecological interactions, provides the basis for the required mechanistic models.

Biodiversity issues

Current issues surrounding preservation of biodiversity and endangered species relate to the continuous loss of the genetic resources of the earth. The biota receiving most of the present concern have been reduced by the direct actions of man: harvesting forests, replacing natural biotic communities with agriculture, emitting dangerous pollutants, and introducing species from other regions. In the future, biota will likely be threatened also by changing extremes in climate and tropospheric content.

The relevant time and space scales are of quite fine resolution. The data sets must include the day-long or week-long time scales which contain extremes of weather /floods, droughts, late spring and early fall frosts, winter low temperatures/ that are capable of destroying the few scattered populations of a species, or the dominant individuals which control the character of a rare community.

The nature of the biotic data, too, is quite precise, being derived from a thorough understanding of the unique environmental variables which determine the survival of the species or communities. These variables differ from one species or community to another, but often consist of unique combinations of soils and climate features.

Data are almost all of small spatial areas, and many of the temporal steps are quite short as well. General principles are unlikely to be detailed enough to allow predicting the response of biota to shifts in environmental variables by specific biosphere reserves and endangered species.

Agriculture issues

Changing climate will play an important role in the future availability of food, fiber, and forest products of the earth.

There appears to be general agreement that the geographic distribution of crop productivity is more related to human actions than to environmental constraints. The problem for global change studies is to define the current environmental constraints which define the potential presence or absence of each crop in differing regions of the globe, and to apply those constraints under scenarios of changing geography of climate.

The soils aspect is particularly important in estimating the future agricultural potential of crops because soils unsuitable for growth of crops may dominate regions which become otherwise climatically suitable. The geographic implications to agriculture of changing climate produce an issue of paramount importance to a global population which continues to grow rapidly.

The time scales of the issue are not easily determined because they depend on human abilities to adapt to ambiguous but clearly changing weather. The space scales of concern are tens of meters to kilometers, defined by soil capability classifications.

Forestry issues

Future availability of forest products is very uncertain. Direct choices by society will determine hardwood forest product availability during the next few decades.

However, human activities which produce changes in climate and atmospheric chemistry may indirectly define softwood futures. The circumpolar boreal forest in the northern hemisphere contains most of the softwood growing stock of the world. Climates that occur nowhere today in the boreal forests may soon displace the boreal temperature and precipitation regimes under which the northern ecosystems currently exist.

The critical datum determining this issue will be the rate of climate change. The critical process to be understood will be forest succession which defines the rate of forest response to climate change. Depending upon migration rates, tree species adapted to changed conditions may also not be capable of migration to the newly available sites.

The space scales are those of perhaps tens of kilometers in terms of distributions of climate, and soils features. The time scales are years to tens of years, corresponding to transient responses to changing climate by long-lived trees and forests. The small spatial area is required to handle the causes and consequences of the processes of forest succession and species migration.

Chapter II

PEDOSPHERE

Definition of soils and pedosphere

Of course everybody seems to know what soils are, but not many people know why they exist on the earth or what their important functions are. From earliest childhood, we walk on soil and think of it as a solid foundation or dirt under our feet. On the other hand, we know that soils are habitats for living plants, providing trees and grasses with rooting space and anchorage. Many even know that soils provide plants with nutrients and water for their life. An agriculturist or a gardener will further know that soils are the surface layer of the earth which must be ploughed, fertilized, irrigated or drained, and kept free of weeds in order to grow cultivated plants. But knowing all these simple facts is not enough to understand these specific bodies of nature, to manage them, to improve their natural capability, to increase and maintain their productivity, and to sustain their diverse ecological and economic functions for the benefit of the biosphere and mankind. We have to know much more about soils, looking at them from different points of view, to know and understand them a/ as natural bodies, b/ as components of the geosphere-biosphere system, and c/ as natural resources for economic development.

Such an integrated view of soil became possible only with the development of soil science at the end of the last century, when DOKUCHAEV, HILGARD and others proposed a new scientific concept of soil as a specific body of nature which developed historically in time and space at the land surface due to continuous and simultaneous interactions through time of the following soil-forming factors: a/ the lithosphere, b/ the atmosphere, c/ the hydrosphere, d/ living organisms and products of their life, and e/ landform or the relief of the locality. Presently, man is considered to have a significant influence on soils.

Throughout history, there was no specific definition of soils in their many-sided totality because it was not required. Instead there existed a simple common understanding of soils, which fully satisfied the users. It was enough to define them as the surface layer of the earth capable of producing and supporting plant growth. However, with the development of social, economic and ecological problems of the last century, with the progress of production and technology caused by the technological revolution, and with the advance of machines and chemicals in agriculture, the need for a new scientific approach and definition of soils has become pressing. The development of soil science became an answer to this growing need, and with this came a new definition of soils.

We currently describe a soil as having been formed in situ with strata or horizons of earthy material that have properties and qualities which have developed under a combined effect of parent rock, climate, living matter, relief, and age of landform. The widest definition of soil might be made using the system approach: soil is a complex, polyfunctional, open, polyphased, structural system within the surface part of the lithosphere.

Soils cover the earth's land surface and the bottom of shallow waters as part of a continuum or mantle, except on bare rock. This continuum is called the pedosphere /from Greek, pedon=ground/. The pedosphere functions as the earth's geomembrane, which is, up to a certain degree, analogous to biomembranes of living organisms /ROZANOV, 1988/. It is the skin of the earth, through which the perpetual exchange of substance and energy between other geospheres proceeds. As a geomembrane, the soils regulate this exchange, passing through some substances and flows of energy, reflecting or retaining, and accumulating others by its surface, or thickness.

The pedosphere in the biosphere-geosphere system

The earth's biosphere-geosphere system consists of several interacting strata covering the nucleus of the globe: outer space, atmosphere, hydrosphere, biosphere, pedosphere, lithosphere, mantle /see Figure 2/. The earth's biosphere is made up of terrestrial and aquatic biospheres. Land only has two main structural and functional layers: the above ground bioatmosphere and below ground biolithosphere.

This concept assumes that the below ground biolithospheric layer of the land's biosphere is the pedosphere, which develops and exists at a junction and as a result of interaction between the lithosphere, atmosphere, hydrosphere and the biota of the planet /Figure 2/. The pedosphere is simul-

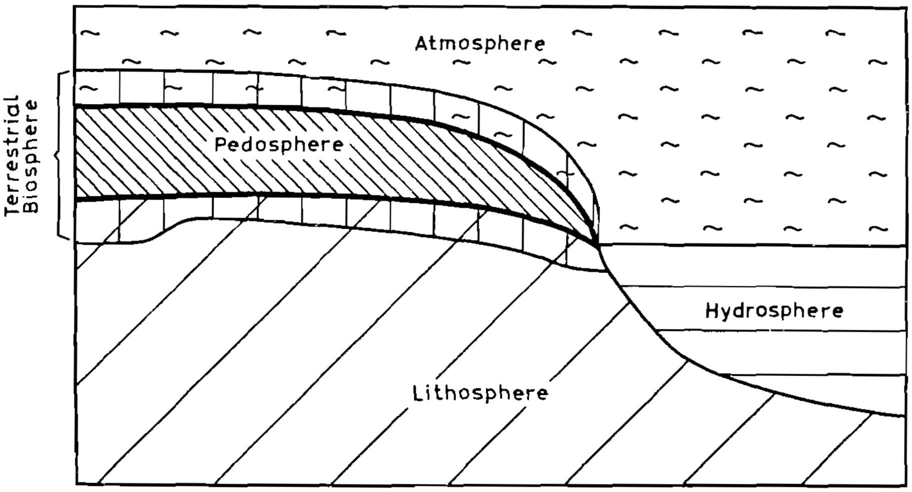

Figure 2. The pedosphere in the biosphere-geosphere system

taneously a component of the lithosphere and of the biosphere, a major support, and the result of life.

Using this approach, it is possible to give description of the pedosphere according to its function and structure. Functionally, the pedosphere, as the upper layer of the lithosphere, is loose and porous, inhabited by biota, and permeable for atmospheric gases and moisture. Because of its porosity, soil is habitable for organisms, and it exercises its geomembrane function as a regulating mechanism within the biosphere-geosphere system. As a subsystem of the land biosphere, the most important and most intensive interactions between biota and all kinds of abiotic substances take place within the pedosphere. Functionally, the pedosphere includes any solid-phase substratum which is capable of exchanging gases and moisture with the atmosphere, hydrosphere, and lithosphere, and of supporting the life of autotrophic and heterotrophic biota. So the pedosphere is the strata of below ground functional layer of the land biosphere.

The majority of the processes within the pedosphere are not completely reversible. Some are irreversible processes such as weathering of silicates and leaching. Others are cyclic but not completely reversible processes such as biological turnover, and formation and mineralization of humus. Due to such irreversibility of soil processes, many residual or new solid-phase compounds occur within the pedosphere /RODE 1947; YAALON 1971/. The annual formation of such compounds is very small and can hardly be detected. But if these processes function for a long time /n.10^2-10^5 years/, these solid-phase compounds gradually accumulate within the pedosphere and form the pronounced pedogenic features of soil formation such as humus, salic, argillic, cambic, and other horizons.

The process of the accumulation of the various combinations of these pedogenic macrofeatures is usually called a soil-forming process, that means, a process which changes the initial solid-phase lithospheric structure and composition into the newly formed pedospheric solid-phase structure and composition /JENNY, 1941;RODE 1947/. These pedogenic features are most pronounced in those cases when the upper layer of the lithosphere is neither renewed by erosion or sedimentation nor mixed with the deeper layers. In the cases of stable landscapes and long-term functioning of the processes in the pedosphere, the gradual accumulation of solid-phase results takes place and forms well-differentiated soils /JOHNSON and WATSON-STEGNER, 1987/.

It is important to note that the pedosphere functioning as a zone of below ground biosphere forms rapidly - a few months and years. The pedosphere as a specific structural solid-phase anisotropic subsystem needs much more time /n.10^2-10^5 years/ to become a well-developed, vertically and horizontally differentiated mantle which we call the pedosphere. So, when we consider the pedosphere in a structural sense we usually mean the attributes of the solid phase of the soil profiles and bodies.

The general development of the pedosphere can be visualized as a sequence. The initial contact and interaction of the atmosphere, hydrosphere, biota with the upper lithosphere layers distinguish the pedosphere as a zone of biosphere functions. With longer-term biosphere interactions the pedosphere develops a three-dimensional anisotropic structure. After its formation, the pedosphere strongly regulates and controls the present and future functioning of the biosphere.

Vertical structure of the pedosphere

The pedosphere has its own specific structure. Every natural soil has a vertical pedogenetic anisotropy as the result of the depth of action in situ of the factors and processes of soil formation. The vertical sequence of different layers in a natural soil is the system of genetic soil horizons that comprises a genetic profile, or soil body.

In general each soil, as a polyphase body within the pedosphere, consists of different types of depth distributions in any given moment. There are temperature profiles, moisture profiles, soil solution profiles, macro and microbiota profiles, and solid-phase profiles. The first three are mainly functional; they are very labile and change very fast /n.10^{-1}-10^{1} years/ in the process of biosphere functioning. The solid-phase forms the more stable soil framework and is characterized by the combination of interrelated horizons which generally differ in soil texture, soil structure, mineralogical and chemical composition. Many kinds of soil horizons are recognized and combinations and sequences of horizons give rise to a large number of unique soils.

Soil as a "block of memory" of the biosphere-geosphere system

Soils and the pedosphere as a whole, are not only a rooting medium for plants and a source of bioproduction; they are also organized and structured natural entities. The main features of environments that existed during soil formation and subsequent changes are reflected and recorded by the pedosphere in its own properties. Every soil body is a "block of memory" of past and present atmo-, hydro-, bio- and lithospheric interactions. It can be said that the pedosphere is the product and block of memory of biosphere-geosphere functioning /TARGULIAN et al. 1979/.

Soil properties have different capacities for recording past and present environments. This strongly depends on the characteristic response time /CRT/ of the individual features and processes, and refers to the time required for a given soil feature to come into quasiequilibrium with the environmental conditions /YAALON, 1971/. The general scheme of the CRT in soils is as follows /ARMAND and TARGULIAN, 1974/:

CRT of soil gaseous phase	$\sim 10^{-3}$ to 10^{-1} years
CRT of soil liquid phase	$\sim 10^{-2}$ to 10^{0} years
CRT of soil micro- and macrobiota	$\sim 10^{-1}$ to 10^{2} years
CRT of soil solid phase /mineral and organic/	$\sim 10^{0}$ to 10^{6} years

The time spans shown as orders of magnitude are only illustrative of the wide range of times involved. For example, some biotic attributes can change much slower than some solid-phase features. It is concluded that the gaseous, liquid, and biotic soil features will reflect the environmental changes much faster than the solid-phase soil features. Although the solid-phase features will reflect the environmental changes slower, they retain a record of environmental changes much longer than gaseous, liquid and biotic attributes.

Thus the solid-phase features of soil profiles are the more important recorders of environmental conditions. Different soil solid-phase properties have different CRT and consequently differ in their capacity to record prior change. The faster soil-forming processes and corresponding soil properties may record past environmental changes for years, decades, and even centuries. Examples are litter-leaching and decomposition, soil structure formation and degradation, salinization and desalinization, gleyzation and oxidation, humus formation and decomposition. The slower processes and their corresponding soil properties may record environmental changes for millennia to millions of years. Examples are clay transformation and translocation, rubification, and different types of deep weathering. The age of soil memory depends on the age of a soil, that is, the duration of soil forming and weathering processes which acted in situ in each specific place.

Many buried soil bodies and patterns reflect past geological environments /see Chapter V/. The soils of the existing pedosphere generally consist of complex combinations of stable, inherited and often relict properties of pre-Pleistocene and Pleistocene weathering, lithogenesis and pedogenesis, inherited and/or evolving properties of Holocene weathering and soil formation, and more recent properties caused by human-induced transformation. These very complicated combinations serve as records of the processes of biosphere-geosphere interactions and the processes of the evolution of these interactions over time. Pedologists are learning, step by step, to "decode" the soil properties information into environmental change information /TARGULIAN and SOKOLOV, 1978/.

The recognition and geographic delineation of soil as a "block of memory" has great importance not only in pedology and soil science but also in paleogeography, ecology, geology and other earth sciences. The correct "reading" of soil-memory information will be useful to separate past and present soil changes and to assist in forecasting the future changes. Knowledge of different components of a soil as "block of memory" and of the rates of changes of solid-phase properties is one of the most challenging tasks for understanding future pedosphere changes.

Main functions of the pedosphere

The biospheric, hydrospheric, atmospheric and lithospheric functions as well as the fertility of soils are determined by the properties and attributes of the whole soil body.

The first most important function of the pedosphere is biospheric. The pedosphere supports and regulates many biotic processes. Plants receive their mineral nutrients and water from soils to build up their biomass. This plant biomass becomes the source of nutrition for animal and man. Biogenic chemical elements accumulate in a soil in the form of available chemical compounds. The biospheric function gives rise to the specific soil quality commonly known as soil fertility, which is the ability of a soil to regularly supply plants with elements of mineral nutrition and water, in addition to simultaneously providing favorable physical and chemical conditions for plant growth. Soil fertility is absent on hard rocks and only weakly expressed on loose rocks of the lithosphere from which soils are developing. Natural soils vary widely in their fertility. Gradually man has learned how to manage soil fertility and soils with low production capacity to transform infertile soils into more productive ones. Irrigating deserts, draining swamps, leaching excess salts and adding fertilizers are examples of such transformations.

Although soils have the capability to support life, they may also have certain properties detrimental for some organisms. They may be too shallow, too dense, too acid or too alkaline, too dry or too wet, too deficient in nutrients or too toxic in soluble salts to provide a favorable environment for plants and animals. The distribution and geography of natural vegetation is closely connected with the distribution and composition of soil cover.

The pedosphere accumulates active organic matter /humus/ and the chemical energy bound to it. Living organic matter rather quickly decomposes into simple chemical compounds after the death of the organism. Part of the dead organic matter is transformed into soil humus or complexed with clay and oxides, which may be preserved for hundreds and thousands of years.

The second global function of the pedosphere is to be an interface and a zone of interaction itself. Due to its "boundary" position within the biosphere-geosphere system, the pedosphere sustains, regulates and controls many biotic and abiotic turnovers and fluxes of substances. The important part of biogeochemical turnover of substances takes place between plant and soil and has an ascending-descending character /so-called small biological turnover/. The plants take from the soil the elements of mineral nutrition which, through a number of intermediate stages /plants-animals-microorganisms/, are again returned into the soil after biotic, protolithic, and photochemical organic matter decomposition.

At the same time soils are the starting point for the migration of the soluble and nonsoluble substances within and through ecosystems. All these substances may be mobilized and leached out of the soil by atmospheric precipitation into the ground and surface waters, some to the ocean, where the aquatic biota use some transported nutrients. Most sedimentary rocks are formed from materials derived from the pedosphere. At a later time, these rocks may be exposed, undergo weathering, and give rise to new soils. This is the so-called big geological turnover of substances.

The third global function of the pedosphere is atmospheric. Soils contribute to the chemistry, moisture and heat balance of the atmosphere. As a porous system, the soil contains pores of different sizes and configurations forming a network of interconnected channels throughout the soil volume. A large part of the pore space is inhabited by roots and by mezo- and microbiota. Due to soil porosity and high density of intrasoil biotic population, the pedosphere exchanges various gases with the near-surface atmosphere: absorbing oxygen, and exuding carbon dioxide and a number of other gases such as methane, hydrogen, hydrogen sulphide, nitrogen oxides, and ammonia. Soil respiration has daily, seasonal and annual dynamics specific for each soil ecosystem. Soil evaporation influences water vapour of the atmosphere and soil albedo.

The fourth global function of the pedosphere is hydrospheric. The pedosphere redistributes water into various land hydrological fluxes. Due in part to porosity and water permeability, soils differ their ability to transform precipitation into infiltration, surface runoff, subsurface intrasoil runoff, and groundwater runoff. The chemical composition of precipitation is also altered when it comes in contact with the soil surface and percolates through the soil body. Due to its porosity, friability, specific surface area and surface activity of solid particles, the pedosphere serves as source, filter and sink of substances during atmosphere-pedosphere-hydrosphere interaction. Soluble mineral and organic substances are realized to percolating and become part of the hydrogeochemical, vertical and lateral fluxes within and through soil. The pedosphere is also the source of solid particles removed by erosion and is often the sink where the materials are deposited.

Because of the sorption and exchange capacity of soils, they filter and absorb many substances from the waters passing through. The hydrospheric functions of the pedosphere affect both the lateral differentiation of the geochemical solid substances at the earth's surface and the chemical composition of the hydrosphere itself.

The fifth function of the pedosphere is lithospheric. As a naturally formed and stratified solid-phase mantle, the pedosphere protects the earth's lithosphere from destructive impacts of the exogenic forces. It buffers and regulates these destructive processes, by acting as the "dynamic" geoderma or skin of the earth. The development of the pedosphere reflects the mutual relations and dynamic equilibrium between different forces and processes: a/ the vertically-acting exogenic processes /weathering and soil formation/, b/ the laterally-acting exogenic processes /denudation, transportation and deposition of the solid particles/, and c/ the endogenic forces /tectonic uplift and subsidence, volcanic activity/.

In each climatic and geomorphic setting, the presence and degree of expression of many soil properties strongly depend upon the relations of the intensities of these groups of processes. Those most differentiated and deeply weathered soils, i.e. ferralsols, usually develop when weathering and soil formation processes have been active for a long time. Shallow, stony and weakly-developed soils occur mainly where the land surface has been periodically rejuvenated either by erosion or by accumulation of recent sediments.

All these global functions of the pedosphere are realized in different qualitative and quantitative terms in different parts of the globe, depending on the natural or anthropogenic landscape of the area, on the natural zone. The totality of the small site specific soil processes combine to form the powerful process of global functioning of the pedosphere.

Spatial and temporal limitations of the pedosphere: Soil as a finite and conditionally renewable natural resource

Soils represent a high capacity buffer media of the biosphere, which may buffer and can moderate - up to a certain limit - the various stresses caused by:

- environmental factors, as climatic droughts or too humid conditions, natural air pollution, volcanic activities, temperature extremes, etc., and/or
- human influences, as intensive, fully-mechanized and chemically controlled crop production; liquid manure of large-scale animal husbandry farms; wastes and waste waters originating from industry, transport, social and rural development, urbanization, recreation; pollution from various sources, etc.

The pedosphere, according to its functional and structural peculiarities, has its own specific spatial and temporal limitations. Thickness and area are its main spatial characteristics. In comparison with the atmosphere, hydrosphere and lithosphere, the thickness of the pedosphere is very shallow, because the pedosphere is marked out from the general biosphere-geosphere system not as a sphere with the prevalence of one physical phase /gaseous, water, solid phase/, but as a relatively shallow sphere of atmospheric, hydrospheric, biospheric and anthropospheric interaction within the upper layers of the lithosphere.

Functionally, the thickness of the pedosphere equals the thickness of the upper layer of the lithosphere involved in such regular annual interactions. Often soil thickness is defined as the thickness of the rooting zone. It is a practically important, but rather narrow, criterion when taking into consideration only the bioproductive and biogeochemical functions of the soil. It is clear that not only biotic but all of the main soil functions /atmospheric, hydrospheric and lithospheric/ should be taken into consideration when defining the functional soil thickness.

The first spatial pedospheric parameter is total soil thickness. In spite of the shallow thickness the whole pedosphere strongly controls and regulates the interactions between all spheres, as the real geomembrane or geoderma. It should be stressed that this very thin sphere within the whole biosphere-geosphere system is very vulnerable because it is influenced by all environmental changes and can be easily deteriorated and even destroyed. The most fertile topsoil /about 0.1-0.5 m/ limits the depth of possible agricultural activity and leads to contamination by pollutants, destruction and even complete soil removal of the land surface due to human-induced erosion.

The second spatial pedospheric limitation is area. The total area of the pedosphere depends on the earth's land area /149 million km^2/. But the real area of the pedosphere is limited by 95 million km^2, that is, 64% of the land area is now covered by more or less bioproductive landscapes and soils. The remainder of the land area /36%/ is occupied by glaciers, lakes, rivers, lifeless deserts, rocks, sands, human settlements and constructions, human-made badlands, etc. /ROZANOV, 1977/.

The pedosphere has finite spatial limitations in depth as well as in area.

The third important limitation of the pedosphere is the temporal limitation of soil functioning, formation and evolution. This problem is closely connected to the very significant problems of soil and pedosphere renewal after natural and human-made deterioration and destruction. The time needed for the natural formation of a mature and well-developed soil body, which has reached /quasi/equilibrium with the environment, varies depending on soil features, soil type, soil processes and environment. The whole set of rates and characteristic times of soil functioning, soil formation and evolution processes embraces nine orders: from the fastest /10^{-3} years/ to the slowest /10^6 years/, as mentioned above.

The whole amplitude of soil-functioning and soil-forming process rates keeps partly within the bioecological and partly within the geological time scales. Only part of the soil features can be formed, changed and renewed by natural processes within the biota- and human-life time scales. It also means that significant soil properties /such as organic matter content and distribution, texture and clay minerals differentiation, total depth of the topsoil and whole soil profile, and total content of clay will have no chance for renewal by natural processes if they become changed and deteriorated by human action. In other words, soil fertility is exploited by agricultural human activity based on some basic soil properties which have been formed by very long-term processes of weathering and soil formation and could not be renewed in a human-life scope. In fact, in the past and at present man exploited and exploits the world's "soil treasures" accumulated over millennia and hundreds of thousands of years of natural soil formation and evolution; these treasures should not be exhausted.

We now know of the many types of human impacts which have, particularly over the last fifty years, affected not only labile and dynamic soil properties but also the more stable and long-term formed properties. These may be very fast, sharp, and deep changes of the soil body and cover during one-two years /irrigation or drainage, combined with deep tillage and strong chemical attack/, or very gradual, latent changes which can imperceptibly accumulate for a long-time, and then suddenly blow up as a "soil degradation bomb" /chemical soil pollution, humus and structure degradation, deep erosion, etc./. In all these cases, it should be stressed that human-induced forces on soils and the whole pedosphere are often accompanied by deterioration or even complete loss of very significant long-formed natural soil properties and even soil bodies and soil patterns.

One can conclude that the pedosphere as a whole, as well as the separate soil bodies and soil patterns, cannot be considered as a completely renewable natural resource.

The pedosphere is functionally and structurally a very important and obligatory subsystem within the biosphere-geosphere system, and at the same time, a necessary conditionally and partially renewable natural resource for human society. All the useful properties of the pedosphere, particularly the unrenewable ones, should be carefully protected and saved for future generations.

Chapter III

SOIL COVER OF THE WORLD

Historical evolution in time and space

The soil cover is characterized by its composition, i.e. the set of soils that constitute the cover, and by its spatial organization, i.e. the distribution and combination of different soils in accordance with horizontal and vertical hydro-geochemical interrelationships.

The beginning of the formation of the earth's soil cover apparently coincides with the initial phases of pedogenesis as a global process /GERASSIMOV and GLAZOVSKAYA, 1960; YAALON, 1963; TARGULIAN et al., 1986/. The initial expansion of biota from the sea to the land did supposedly take place as early as the Lower Paleozoic, more than 500 mln years before present /SINITSIN, 1967/. These biota were micro-organisms, that could only produce a primitive soil formation, soil-films, a few mm deep. These thin films apparently formed, as microspots over the abiotic land surface. A real soil cover was inexistent. It was a 'primary' phase of soil development.

At the end of the Silurian, about 400 mln years before present, biota were actively conquering land, Psilophytes, devoid of root systems and adapted to high humidity of the sea coasts. Fluvisols were forming, characterized by surface accumulation of organic matter, gleyification, and constant inflow of mineral sediments from water streams /FRIDLAND and BUYANOVSKIY, 1977/. Other weakly-developed soils, Regosols and Leptosols, were formed together with the Fluvisols. They are the earliest soil formations of the earth. This phase of evolution of the soil cover can be named 'sporadic' as the spots and strips of Fluvisols were sporadically distributed over the abiotic or weakly biotic background.

By the end of the Devonian, about 350-360 mln years before present, there was a drastic change of the earth's vegetation: ferns and horsetail, root-possessing plants with high biomass production, spread in subtropical and tropical conditions. It is probably during the Devonian-Carboniferous that soils related to the Ferralsols have appeared for the first time. The soil cover became more complex in composition, but still did not entirely cover the land surface. This phase of evolution of the soil cover can be named 'intermittent'.

In the Permian, 285-240 mln years before present, in correspondence with the differentiation of the earth's climates and landscapes, the soil cover was enriched by new soil groups. Concurrently, there was a further differentiation of the already existing groups. Thus, the Regosols and

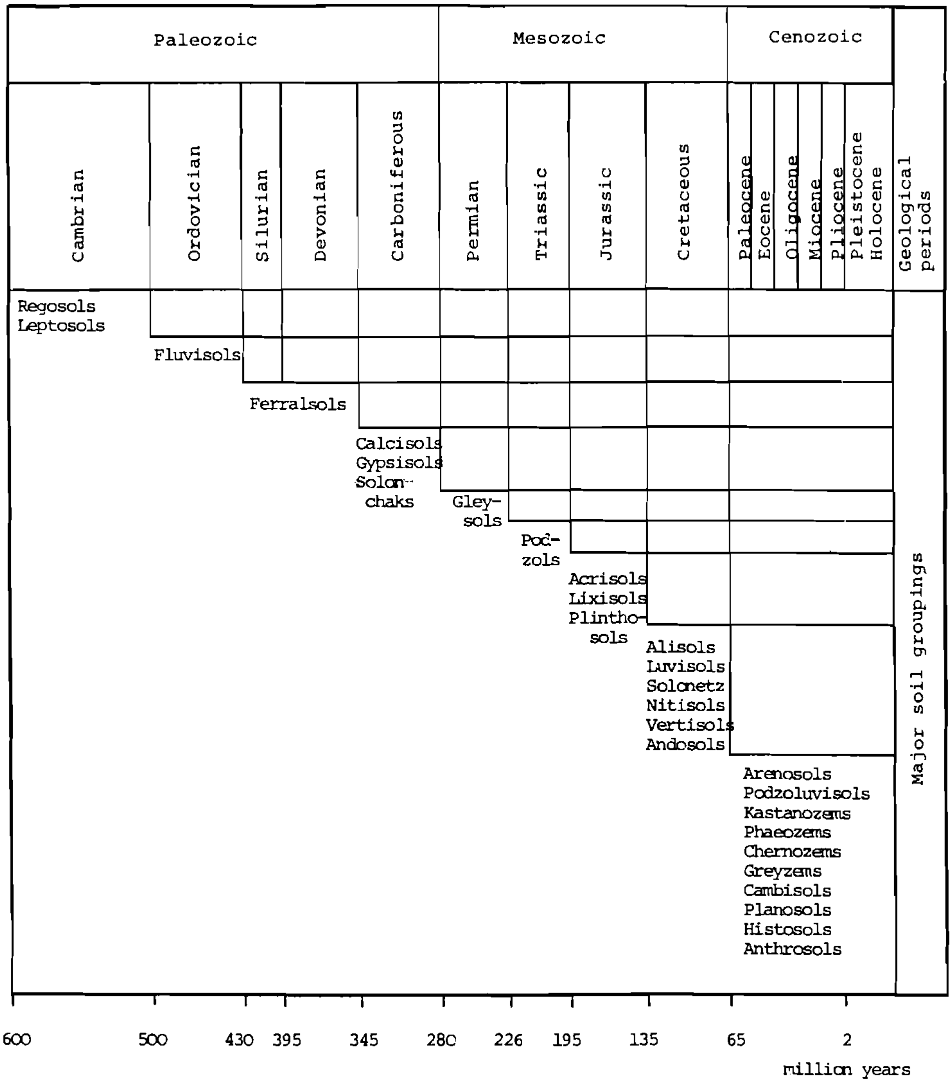

Figure 3. Evolution and diversification of the World's soil cover. /Tentative scheme/ /adapted from FRIDLAND and BUYANOVSKIY, 1977/

Leptosols were significantly enriched by the diverse soils of the vast deserts of the Permian and by gelic soils during the Permian glaciation. The intermittent soil cover was gradually evolving into a continuous cover. It was this fourth stage of natural evolution that developed into a soil 'continuum'.

In the subsequent phases of evolution of climates and biota, the composition of the soil cover was becoming more differentiated. Volcanic lava's and ashes which were formed during the Tertiary and the Pleistocene gave rise to Vertisols and Andosols. The most recent development is the formation of Chernozems and Kastanozems, which correspond to the development of the gramineae and of steppic landscapes on loess. At the same time, there was greater internal enrichment of each group due to more diverse genetic properties of soils composing these groups. This diversification was directly associated with the colonization by these groups of new areas with different natural conditions. Thus, the Gleyic and Umbric Gleysols appeared in the boreal zone only in the epoch of the Pleistocene glaciations. Figure 3 is an attempt to represent the evolution and diversification of the soil cover of the earth during the different geological periods.

An analysis of the evolution of the earth's soil cover in time and space gives grounds to highlight the following important trends:

- As a specific sphere of the earth, the soil cover began to develop, supposedly, in the Paleozoic /Cambrian-Silurian/ and till present it passed through four phases of natural evolution: 1. primary /weakly biogenic/, 2. sporadic, 3. intermittent, 4. continuum. This sequence may have repeated itself at different geological periods.

- Different genetic soil groups that form the soil cover are historical categories. Each of them emerged in a certain geological epoch of the earth's evolution.

- In the course of its historical evolution, the composition of the soil cover was developing in two directions: 1. growth of the number of the genetic soil groups, and 2. diversification of the inner composition of each group.

- The process of diversification in time is also characteristic for the interrelationships of the soils in space, i.e. for the composition, structure and geometrical forms of the soil associations.

- The historical evolution of the natural soil cover is closely linked with global evolution of the factors of pedogenesis. This correlation explains that the global evolution of the soil cover, related to the evolution of the factors of pedogenesis, is irreversible /GERASSIMOV and GLAZOVSKAYA, 1960; YAALON, 1971/.

With the emergence of man in the Pleistocene the soil cover of the earth gradually entered the modern anthropogenic phase of development. This phase is characterized by two opposing trends of transformation:

1. Homogenization of the composition and structure of the soil cover for agricultural use, aimed at the formation of a fertile layer with properties useful for agricultural production;

2. Heterogenization of the soil cover, as a result of the diversity of anthropogenic activities, and because of a degradational trend of evolution of the soil which may lead to the depletion and even destruction of the soil cover. The result of the anthropogenic influence is a greater diversity of the soil cover. The magnitude of transformation of the soil cover during

this phase can be compared in importance with some geological effects on the pedosphere. However, in the case of geological evolution, restoration and further development of the soil cover took hundreds of thousands of years, a time scale which is inacceptable for the human society.

A descriptive overview

The present soil cover of the world comprises 28 major soil groupings. These separations at the highest level of generalization were made on the basis of the effects of different soil forming processes as far as these are reflected by observable and measurable attributes.

The classes which are distinguished at this first categorical level were determined through international cooperation, taking into account present knowledge of the composition of the world's soil cover. The nomenclature used is the one of the FAO/UNESCO Soil Map of the World legend /FAO, 1988/.

The 28 major soil groupings, briefly described below, are listed in nine sets on the basis of the main factor which has influenced the formation of these soils /DRIESSEN and DUDAL, 1989/. The estimates of the global distribution of the major soil groupings are based on the FAO/UNESCO Soil Map of the World /FAO, 1971-1981/.

1. Soils characterized by a strong accumulation of organic material, generally associated with waterlogging:
   - Histosols are organic soils which occur mainly in boreal areas but which also occupy important surfaces in temperate and humid tropical regions /240 million ha/.

2. Soils of which the formation is conditioned by the particular properties of their parent material:
   - Vertisols, characterized by churning of soil material as a result of swelling and shrinking. They occur mainly in tropical and subtropical regions with a marked alternation of wet and dry conditions. Their formation is linked to materials consisting of swelling clays /340 million ha/.
   - Andosols, characterized by the presence of amorphous alumino-silicates resulting from the weathering of volcanic material. They occur over a wide range of climatic conditions in connection with the global distribution of volcanic activity /160 million ha/.
   - Arenosols, characterized by a sandy texture and a lack of distinct profile development. The major extension of Arenosols is in the dry area of Africa. However, they also occupy large areas in Australia, Brazil, and the Near East /400 million ha/.

3. Soils of which the formation is markedly influenced by the relief and physiographic setting:
   - Fluvisols, which occur in major alluvial plains under different climatic conditions and which are characterized by regular accretions of fresh sediments /320 million ha/.

- Gleysols, characterized by marked groundwater influence. They occur under different climatic conditions but their major extension is in boreal regions /620 million ha/.
- Regosols, characterized by medium to heavy texture and a lack of distinct profile development because of low temperatures, prolonged dryness or erosion. The major extension of Regosols is in the arctic regions and in the arid tropics and subtropics /900 million ha/.
- Leptosols, characterized by shallow depth generally associated with steep relief and erosion. The major extension of Leptosols is in the montane regions throughout the world /2 260 million ha/.

4. Soils of which the formation is conditioned by a limited pedogenetic age or by rejuvenation:
   - Cambisols, characterized by weathering in situ reflected by a change in colour, texture or consistence. Cambisols occur mainly in temperate and boreal climates or in subtropical and tropical regions where erosion limits profile development /825 million ha/.

5. Soils of which the formation is markedly influenced by a humid tropical or subtropical climate:
   - Ferralsols, characterized by a residual accumulation of sesquioxides as a result of strong weathering. These soils occur essentially in the humid tropics on the continental shields of South America and Central Africa /1 000 million ha/.
   - Nitisols, characterized by an accumulation of clay combined with strong weathering. They occur mainly in tropical climates with dry and wet seasons and are linked to intermediate or basic parent materials /250 million ha/.
   - Acrisols, characterized by an accumulation of low activity clays and by a low base saturation /800 million ha/.
   - Alisols, characterized by an accumulation of high activity clays and by a low base saturation /100 million ha/.
   - Lixisols, characterized by an accumulation of low activity clays and by a high base saturation /200 million ha/.
   - Plinthosols, characterized by surface waterlogging over a subsurface layer of plinthite, a mottled clay which hardens irreversibly upon exposure /50 million ha/.

6. Soils of which the formation is markedly influenced by an arid or semi-arid climate:
   - Solonchaks, characterized by a strong accumulation of soluble salts /260 million ha/.
   - Solonetz, characterized by a marked saturation with sodium /100 million ha/.
   - Gypsisols, characterized by a marked accumulation of gypsum /150 million ha/.
   - Calcisols, characterized by a marked accumulation of calcium carbonate /1 000 million ha/.

7. Soils of which the formation is conditioned by steppic climates and which are characterized by a surface accumulation of saturated organic matter.
   - Chernozems, which occur mainly in the boreal steppes /300 million ha/.
   - Kastanozems, which occur in the warm steppes /400 million ha/.
   - Phaeozems, which occur in the prairies and the steppe-forest transition zone /100 million ha/.
   - Greyzems, which occur in the more humid forest-steppe transition zone /30 million ha/.

8. Soils of which the formation is conditioned by humid cool to temperate climates:
   - Luvisols, characterized by an accumulation of high activity clays and by a high base saturation. Their major extension is in temperate and mediterranean regions /600 million ha/.
   - Podzoluvisols, characterized by an accumulation of high activity clays and by a bleached eluvial horizon tonguing into the clay enriched horizon. Their major extension is in cool temperate and boreal climates /260 million ha/.
   - Podzols, characterized by a subsurface accumulation of organic matter, iron and aluminium. Their major extension is in boreal climates /480 million ha/.
   - Planosols, characterized by seasonal surface waterlogging over an impervious subsurface horizon /150 million ha/.

9. Soils of which the formation is strongly influenced by human activities:
   - Anthrosols, in which natural diagnostic horizons have been obliterated by human intervention or in which new layers have been created as a result of human activity /2 million ha/.

Considerable parts of the land surface of the world are covered by non-soils consisting of rock outcrops, ice fields, salt flats and other miscellaneous land units /1 095 million ha/.

The above nine sets, merely indicate common relationships between soil groupings and major soil forming factors. Therefore, the 'climatic sets' are not meant to reflect a strictly 'zonal' distribution of soils: although Podzols occur mainly in boreal climates, they also occur in mediterranean and in humid tropical climates; Ferralsols may occur outside the humid tropics as remnants of earlier more humid conditions; Solonchaks also occur in steppic climates and Planosols do occur in the subtropics as well as in temperate regions. The sets presented above may therefore not be taken as high level classification units.

On the basis of the global inventory of the FAO/UNESCO Soil Map of the World /1971-1981/ it is estimated that of the 13 392 million ha of land that are free of a permanent ice cover, 3 030 million ha are potentially cultivable. The larger part of the world's soil cover is either too cold, too dry, too wet, too steep or too shallow to enable profitable agricultural use.

The potential cultivable area is distributed in a proportion of 71 to 29 percent over the developing countries and the developed countries respectively, that is about in the same proportion as the present distribution of the world's population. The presently cultivated area in the world is estimated at about 1 500 million ha, that is only half of the area potentially available. In developing countries as a whole only 36 percent of the potential cultivable land is used. In the developed countries it is 77 percent. These global figures mask considerable differences in the availability and quality of cultivable land between countries. Land reserves are located in the humid tropical regions of South America and Central Africa, however, in many countries outside the humid tropics land reserves are scarce or inexisting.

When planning for a higher degree of self-sufficiency, it is essential that differences in land resource endowment and in crop production potentials, be fully appreciated. In some countries land reserves are such that cultivation can be expanded to meet national requirements, and even beyond. In other areas the limits of cultivable land have already been, or are about to be, reached and most of the increased production will have to come from the intensification of agriculture on land already cultivated. Certain countries with unfavourable soil and climatic conditions may not have means to meet the food requirements of their populations, even if the level of inputs were to be optimized. In this case implementation of major land improvements to enhance the land resource base may have to be considered.

With the identification of critical areas in various parts of the world, it clearly appears that future needs will have to be ensured by a global food system that establishes complementarity of production between areas of different suitability /DUDAL, 1984/. A thorough knowledge of the world's soil cover and of the changes which it undergoes is essential for the relevant land use planning at international scale as well as at the national level.

Main regularities of soil distribution

The concept of the basic regularities of the earth's soil cover, i.e. of global soil geography, underwent significant changes in the course of the development of pedology.

The original understanding was based on the concept of latitudinal and vertical /or mountain/ soil zonality formulated by V.V. DOKUCHAEV /1951/: '...the principal pedogenic agents are spread over the earth's surface as belts or zones stretched more or less parallel to latitudes... therefore, the soils - our chernozems, podzols, etc. - should inevitably have zonal distribution strictly corresponding to climate, vegetation, etc.' This first zonal concept was used by V.V. DOKUCHAEV and his students to compile, in 1900, the first soil maps of the territory of European Russia and of the northern hemisphere. These maps showed five major soil zones: boreal or arctic; forest; steppe; arid /subdivided into stony, sandy, solonchak and loess deserts/; and laterite. The 'ideal' latitudinal occurrence of these zones was found to be locally 'disturbed' by areas of mountains, stony soils and alluvial soils.

Further studies of the soil cover of different continents and countries have lead to important amendments of the zonal soil concept. It was found, that the soil zones do not always - actually rather exceptionally - have a latitudinal occurrence. They may be stretched meridionally, or have concentric patterns. In one and the same latitude, possibly within one and the same continent, a soil zone may be replaced by another one, as a result of a transition from oceanic to continental areas. No less profound reconsideration was given to the regularities of the mountain soil zonality. The relationship put forward by V.V. DOKUCHAEV, between higher altitude, more humid and cool climates and the corresponding transformation into 'more northern' soil zones, appeared to be more complicated. It was found that the actual regularities of the soil cover in mountain areas are much more diversified and are generally determined by the geographical position and the specific characteristics of a mountain region: altitude, exposure, configuration, topography, area, etc. These new data lead to the formulation of a landscape-geographical, or bioclimatic, or zonal-facial concept of world soil geography /ROZANOV, 1977/. The basic assumption of these concepts is the priority role of climate and the corresponding vegetation in the development of soils over the earth's surface. This relationship accounts for the close coincidence between climatic-vegetation belts and the soil zones. This concept was upheld till the 1960s and was reflected by many soil maps of the world and continents.

Active studies of the world soil cover since the 1950-60s and new survey data disclosed that the above concept is insufficient for a scientific explanation and cartographic representation of the actual diversity of the world soils. The further advancement of the soil geographical ideas was based on two principles: 1. priority of the genetic properties of the soils proper and of their spatial variability; 2. due consideration to the factors of pedogenesis, as reflected in the characteristics of the soils under study. The application of these principles turned out to be a very complicated task, because, besides good knowledge of the world soil cover and environmental factors, it required an advanced genetic classification of the world soils and an assessment of the significance and hierarchy of the whole range of soil characteristics, of the levels of genetic similarity, of the diversity of pedons and soil groups, and of the character and degree of their correlation with the pedogenetic factors. Therefore, the development of knowledge on the main regularities in the world soil cover is now closely linked with the ecological studies of the environment as a whole, with the exploration of the problems of soil classification and with the advancement of accurate soil survey - supported by remote sensing imagery - that allows the testing and amendment of current pedo-geographical concepts and the generation of new ones.

The multiplicity of the regularities that determine the actual world soil cover has now become obvious. Soil spatial variability, diversity and distribution are now recognized to be the result of a combined change of soils and soil forming factors /climate, biota, parent material, relief, hydrology, human-induced forces, paleogeography, duration of soil formation/. The study of the global soil cover enabled the recognition of 'pure lines' of spatial soil changes: climate-induced, biota-induced, parent material-induced, human-induced, etc. Generalizing the vast empiric knowledge of soil geography, it is possible to distinguish 'pure line' spatial changes. They influence the soil cover in combination, however, some of them may have a dominant effect.

Climatic changes. Soils change spatially in accordance with spatial climate changes, while other soil-forming factors are more or less constant. The well-known examples of such soil changeability are the climatic soil zonalities: latitudinal or horizontal, and altitudinal or vertical. Representative examples of 'zonal soils' are tundra Gleysols, boreal Podzols, steppe Chernozems, and humid tropical Ferralsols.

Biota-induced changes. Usually the biota, particularly vegetation, changes in correlation with the climate, lithology and relief, but in some cases, pure biota changes may occur: forest-steppe, forest-tundra, tropical forests and grassland. They lead to soil spatial changes while the other factors are rather constant.

Lithological changes. Soils change in accordance with spatial changes of the soil parent material, while climate and topography are more or less constant. As a result there may be more than one mature soil which has developed and is in equilibrium within a same climatic zone e.g. Podzols on sands besides Gleysols on loams and clays in tundra and boreal ecosystems. Furthermore, some soils, developed from a specific parent material, can spread through different bioclimatic zones: Podzols on sands in tundra, boreal, temperate and humid tropical zones; Andosols on volcanic ashes in boreal, subtropical and tropical zones; Vertisols in humid, semi-humid and semi-arid regions in the tropics and subtropics.

Temporal or heterochronic changes. Soils change spatially in accordance with changes in the age and duration of soil formation while climate parent material and topography are more or less constant. Examples of temporal soil changeability are the chronosequences of Podzols and Podzoluvisols from similar parent materials through different stages of non-podzolized profiles to the mature profiles. The development and spatial differentiation of humid tropical soils through the stages of Regosols, Cambisols and Andosols to Acrisols, Nitisols and Ferralsols are another example of time-induced changes.

Relief-induced changes. Soils change spatially in accordance with changes of macro-, meso-, or micro relief of the land surface. The relief is a very powerful regulator and redistributor of water, solution and suspension fluxes from the top to bottom position of the landscape. Soil changes are caused by spatial differentiation of the hydrological and geochemical effects. Examples of such soil spatial changes are the increasing hydromorphism, gleyization and enrichment in Fe and Mn oxides in the lower part of soil catenas; the increasing of soil hydromorphism and salinity in depressions in semi-arid and arid regions; the formation of poorly drained Gleysols and Histosols on low undissected plains in contrast to the prevalence of well drained soils on the more dissected parts of the landscape.

Lateral transportation-induced changes. Soils change spatially due to the removal or accumulation of fine earth particles of the topsoil. Within a catena such a change may be attributed to the effect of relief. However, inter-regional and inter-continental transfers of eolian dust, volcanic ash and fluvial sediments, have to be recognized a specific cause of soil spatial changeability.

Evolutional or relic changes. Soils change spatially due to different paths of pedogenic and lithogenic evolution on different parts of the land surface. The soil-forming factors can be similar, but the soils can strongly differ by the presence or absence of relic features of Pleistocene and pre-Pleistocene evolution. Examples of evolutionary spatial changeability are the humid tropical Ferralsols and Nitisols evolving from deeply weathered materials dating back to the Tertiary, versus the tropical Cambisols and Andosols developing from rather young, slightly-weathered Pleistocene and even Holocene sediments and young volcanic lava's and ashes. Perhaps it would be sensible to combine this line of spatial soil changeability with the lithological one.

Anthropogenic or human-induced changes. Soil changes due to anthropogenic influences are possibly the most actual, urgent and complicated stage of spatial changeability. It should be stressed that this particular case does not have adequate representation on world soil maps because of its variability. A more detailed analysis of the anthropogenic soil changes is made in Chapter VI.

These 'pure line' regularities are overlapping. Their complicated interaction in space and time has produced the modern soil cover. This brief review clearly demonstrates the correlation of the pedogenic processes and the differentation over the land surface of the biospheric, geospheric and atmospheric processes. Studies of the biosphere-geosphere that would ignore changes of the earth's soil cover, would fail to produce adequate scientific understanding of global change and may lead to erroneous conclusions and fallacious decision-making.

Chapter IV

TYPES OF SOIL PROCESSES AND CHANGES

Soil processes /abiotic and biotic translocation and transformation/

The main factors and processes of soil formation are summarized in Fig. 4.

Weathering and decomposition break down the mineral and organic parent materials of soils and new materials are formed during soil development. The residues from these disintegrating processes and the newly formed substances combine to form the whole soil body with peds making up the pedon.

The formation and development of soils /pedogenesis/ embraces the operation of weathering and soil forming processes, which are determined by soil forming factors of the environment, resulting in soil properties. The properties are exhibited in the soil profile, which is characteristic of the soil type /differing from each other by various diagnostic features/. The visible and measurable attributes of the horizons /layers/ of the profile enable us to visualize the processes which have taken place in the history of soil formation and the factors that operated to control these processes.

Transformation processes /conversion of materials/

They usually operate in situ but may involve some movement, but only over very short distances /µm-mm/ /e.g. by diffusion/. The most significant transformation processes are:

dissolution - precipitation /soluble components/
adsorption - desorption
oxidation - reduction
acidification - alkalinization
weathering - mineral neoformation
decomposition of organic matter - humus formation /humification/
formation /aggregation/ - destruction /regregation/ of soil structure
mobilization /release/ - immobilization /abiotic and biotic fixation/ of plant nutrients

They are all involved in the formation of the soil body from mineral and organic parent materials and they operate further to differentiate the soil into distinct diagnostic horizons.

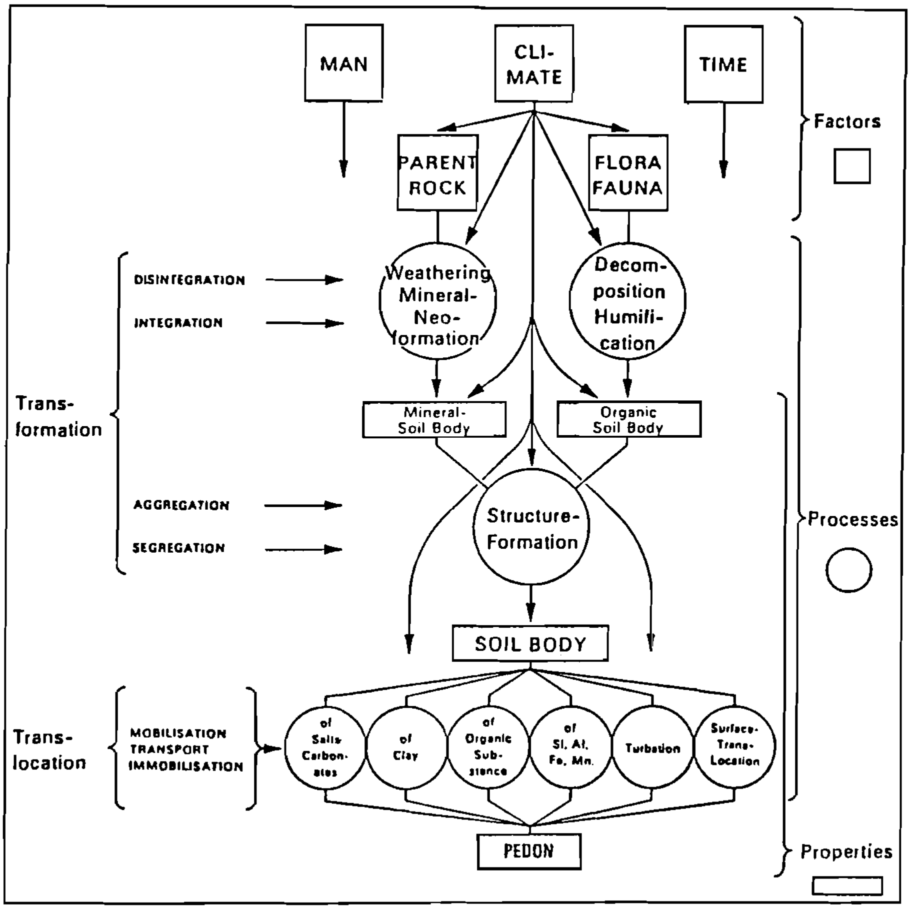

Figure 4. Factors and main processes of soil formation

Transport processes /translocation, migration of the products of transformation/

This involves displacement, sorting and mixing within and on the soil body, resulting in profile differentiation. The causes are: percolating, eroding, ascending and stagnating water; the activity of man and the soil fauna; frost, pressure and forces depending on relief. Translocation starts from mobilization and ends with the immobilization of transported materials. The main transport processes are:

- flow of water /periodical wetting and drying/;
- movement of salts /Na-salts, lime, gypsum, etc./: leaching and accumulation;
- clay transport;
- transport of organic matter;

Table 1. Field characteristics of soil profiles and soil horizons

Areal /environmental/ characteristics	Profile characteristics	Horizon characteristics	
Land form, relief, drainage Relief type microrelief Slope characteristics classes by slope gradient length and shape elevation exposure Erosion classes reasons /wind, water/ type degree hazard Coarse fragments on surface stoniness rockiness Soil drainage classes runoff permeability internal soil drainage altered drainage incidence of flooding Vegetation /crops/ botanical composition indicator plants appearance of plant communities, crop sequence of vegetation	No. Location area geographical coordinates Elevation Position on the relief Depth of profile humus horizon effervescence with dilute acid alkalinity against phenolphtalein wetting zone impermeable layer buried horizon Depth of water table average max. min. actual Parent material Soil taxonomy unit /type, subtype, variety/ Mapping unit	Symbol Depth and thickness Colour Hue when wet Value dry Chroma /Munsell Color Chart/ pattern /mottlings/ contrast abundance size shape Solid particles textural classes coarse fragments stoniness rockiness Soil structure grade of structure types and classes Consistence when wet moist dry	Soil reaction and carbonate status pH effervescence with dilute acid alkalinity against phenolphtalein Special formations concretions pans /depth, thickness, cementing agent/ efflorescence Organic matter and biological channels kinds of organic matter root distribution animals in soil krotovinas Boundary of horizon distinctness topography /shape/ horizontal variation

- transport of plant nutrients;
- Si-, Al-, Fe- and Mn transport;
- erosion /caused by water or wind/ and sedimentation;
- turbation /mixing processes/: bio-, hydro-, cryo-turbation;
- surface movement /solifluction, landslides, etc./: see Fig. 4.

The above-mentioned processes result in changes or in the quantity /gains and losses/ or in the status /form "quality", mobility, availability/ of various soil constituents, which are manifested in the development and changes of different soil properties.

Table 2. Main mineralogical, physical and hydrophysical properties of soils

Properties and time changeability classes		Properties and time changeability classes	
Mineralogical properties		- development type size of soil structure	3 3 2
- parent material	6	- aggregate stability	2-3
- primary mineral composition	5	- dispersity factor	2
- clay mineral association	4	- structure factor	2
- chemical composition of the mineral part	4-5	- total porosity	1
- type and state of amorphous compounds	3	- void ratio	1-2
Mechanical properties		- gravitational - capillar-gravitational - capillary porosity	1 1-2 2
- compaction	1	Hydrophysical properties	
- consistency when wet moist dry	2	- total water storage capacity	1-2
- upper - lower plasticity limit	3	- field capacity	2
- plasticity index	3	- wilting percentage	3
- penetrability	1-2	- available moisture range	2
- compactibility	1-2	- actual moisture content	1
- trafficability	2	- infiltration rate	1
- share of strength	3	- hydraulic conductivity	1-2
- modulus of rupture	3	- capillary conductivity	2-3
Physical properties		- permeability	1
- texture	6	Characteristics of soil air and heat regime	
- particle-size distribution	6	- air capacity	1
- saturation percentage /SP/	6	- composition of soil air	1
- hygroscopic moisture content /hy/	6	- temperature	1
- specific surface	4-5	- heat capacity	3
- particle density	6	- heat conductivity	3
- bulk density	1		
- rate of swelling	3		

*Changeability classes according to Table 4.

Table 3. Main chemical and biological properties of soils

Properties and changeability classes		
Soil reaction and carbonate status		
- pH		2-3
- hydrolitic acidity		2
- exchangeable acidity		3
- acid neutralizing capacity		3
- alkalinity against phenolphtalein		2
- carbonate content		3
Absorption complex		
- cation exchange capacity /CEC/		3-4
- exchangeable cations		3
Ca^{2+}		
Mg^{2+}		
Na^{+}		
K^{+}		
- sum of exchangeable cations		3
- base saturation		3
- rate of diffusion		2-3
Salinity-alkalinity		
- total water-soluble salt content		1-2
- electrical conductivity		
- saturated soil paste		
- saturation extract		
- ion composition of the		
- soil solution		2
- saturation extract		3
- 1:5 aqueous extract		3
Ca^{2+}	CO_3^{2-}	
Mg^{2+}	HCO_3^{-}	
Na^{+}	SO_4^{2-}	
K^{+}	Cl^{-}	
Organic matter		
- organic matter content		3-4
- "quality" of humus substances		3
- stability value		
- fractional composition		
- rate of humification		
Nutrient status		
- "total" quantity	of macro mezo and micronutrients	3
- "available" quantity		1-2
- "toxic limit"		2
- rate of mobilization		2
- rate of fixation		2
- rate of biological immobilization		2
Quantity and status of toxic elements		
- "total" quantity /as potential source/		3
- "mobile" quantity		2
- "available" quantity		2
- buffer-capacity of soils against various pollutants and toxic elements		2-3
Biological properties		
- number and total biomass of soil microorganisms		1-2
- species spectra		2
- enzyme activity		2
- general microbiological activity		2

* Changeability classes according to Table 4.

Soil properties and regimes

The most important and specific characteristic of the soil is fertility, the special ability and unique feature that water, air and available plant nutrients may occur simultaneously in this polydisperse porous system and may cover - to a certain extent - the main soil ecological requirements of natural vegetation and cultivated crops.

Soil fertility depends on the combined influences of various soil characteristics which are the results of soil processes reflecting the mass /matter/ and energy regimes of the geological strata /parent material/-soil-water-plant-near surface atmosphere system. Soil quality is a combination of attributes of the soil which acts in a distinct manner in its influence on the function of the soil for a specific kind of use. Soil quality can be related to soil features, characteristics and properties /BOUMA, 1989/.

The main field characteristics and mineralogical, physical, hydrophysical, chemical and biological properties of soils are summarized in Tables 1, 2 and 3. In Fig. 5 and 6 the characteristics of the solid phases and the moisture regime are schematically illustrated, respectively.

Soil properties are not constants and change permanently due to abiotic and biotic transport and transformation processes under the influence of pedogenic factors /Fig. 4/. Soil regimes express these temporal changes /time dynamism/, which can be systematic or random, fluctuations or trend changes, reversible or irreversible, natural or human-induced.

Changes can be observed:
- in the total quantity of various soil constituents, e.g. clay-, organic matter-, salt-, nutrient- or moisture-content, etc.;
- in their vertical /profile/ distribution: leaching or accumulation; formation or destruction of diagnostic or characteristic soil horizons, e.g. argillic, matric, horizons, duripans, fragipans, calcic, gypsic, petrocalcic, petrogypsic, salic, sulfuric, etc.;
- in their horizontal distribution /due to surface runoff erosion-sedimentation; seepage; flood; etc./;
- in their phase-distribution /wetting-drying; solution-precipitation; cation exchange; etc./;
- in their relative quantities and ratios;
- in their "quality" and functions, e.g. stability /aggregates, organic matter/, solubility /carbonates, salts, organic matter, humus and other organic compounds; etc./, mobility /soil water Na^+, etc./, availability for plants /water, nutrients/; etc.

The most important soil regimes are the moisture-, air-, heat-, salt-, organic matter- and plant nutrient-regime. Their relationships are summarized in Fig. 7.

Time changeability of soil characteristics, properties and regimes

Time changeability of soil properties and regimes show a great variation. Since soil phases /gaseous, liquid, solid, biotic/ have different rates of response to the environmental trend changes and fluctuations, soil properties and regimes which characterize these phases and their interactions need different time-periods to reach a quasiequilibrium status with the environment. This time is defined as "characteristic response time" /CRT/

Soil changes are closely connected with the trend changes, cyclic /daily, seasonal, yearly, perennial/ fluctuations and irregular /random/ time variabilities of the pedogenic factors.

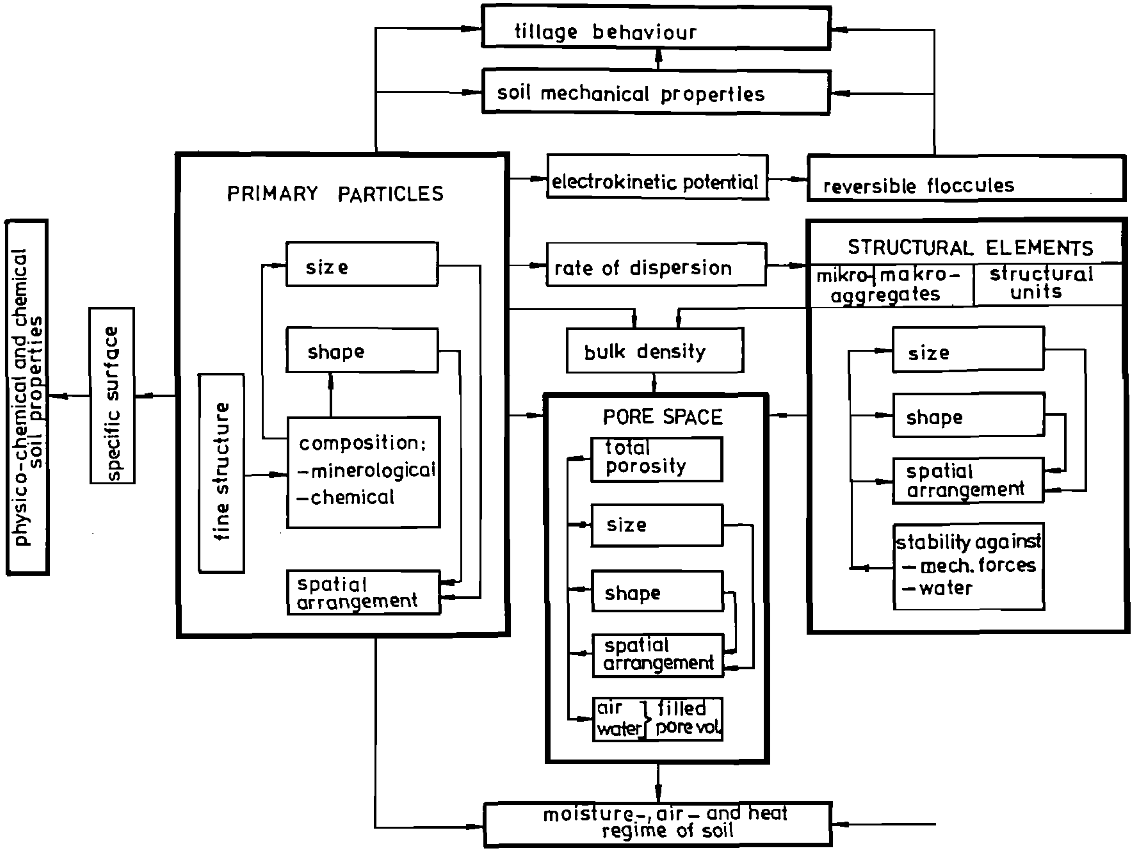

Figure 5. Characteristics of the solid phase of soil

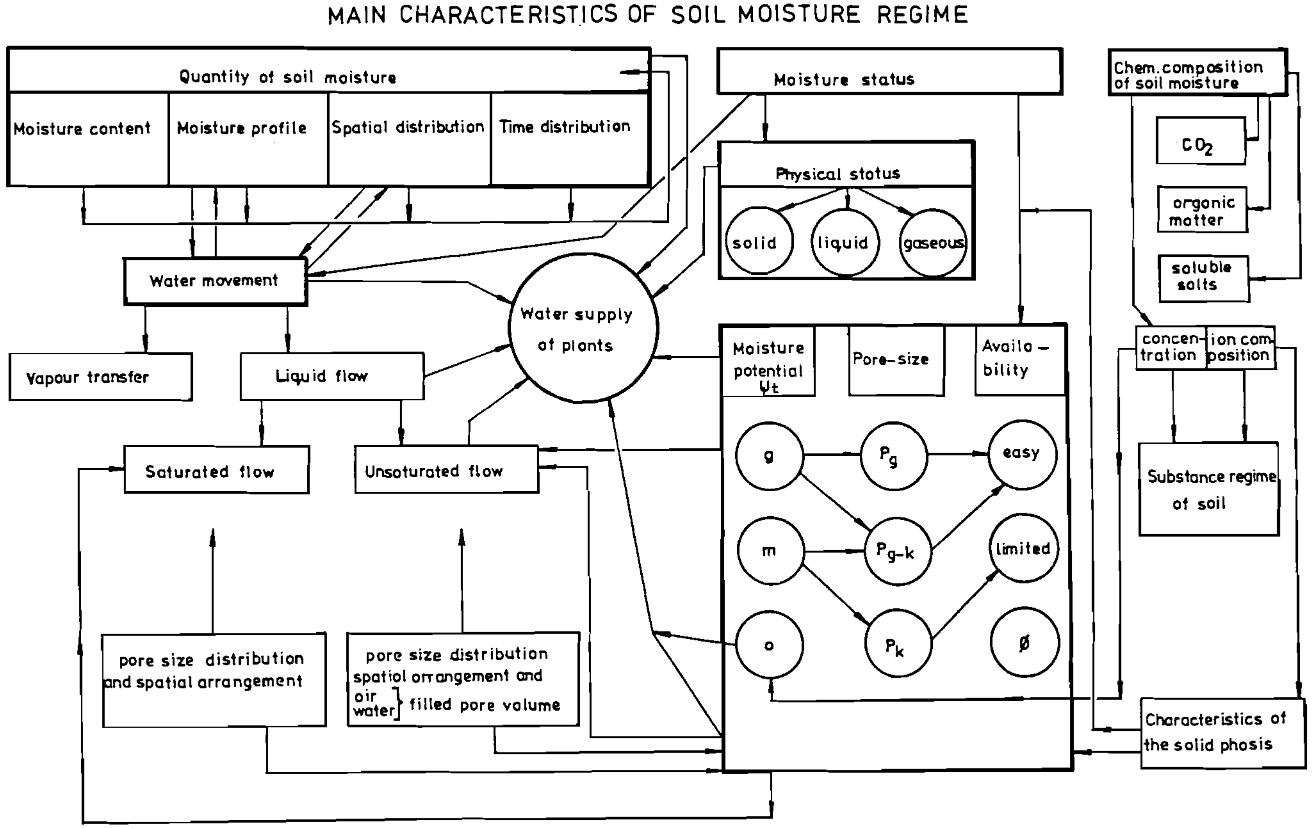

Figure 6. Main characteristics of soil moisture regime. g = gravitational potential; m = matric potential; o = osmotic potential; P_g = gravitational pore space; P_k = capillary pore space

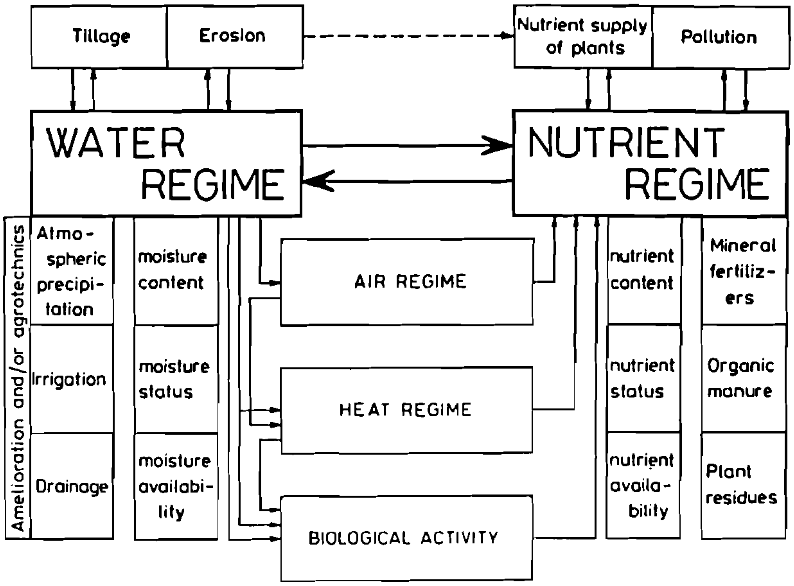

Figure 7. Relationships between the water regime and the nutrient regime of soils

Temporal changeability of the main spheres can be characterized by the following schematical sequence:

atmosphere > hydrosphere > biota > pedosphere > litosphere

$$\xrightarrow[\text{increasing of CRT}]{\text{decreasing of temporal changeability}}$$

Temporal changeability of soil properties characterizing the different soil phases can be approximately described by the following time-sequence:

gaseous phase > liquid phase > biotic phase > solid phase

That is a rough scheme, which has many exclusions, but it is still reflected by the majority of soil properties. Taking into account the complexity of the pedosphere it is impossible to determine the soil temporal variability or changeability by only one characteristic. Each soil process and property has its own response time. Very labile soil properties have CRT, which almost coincides with the characteristics of the atmosphere and hydrosphere. In the contrary, very stable soil properties have long CRT, which is very close to the CRT of soil lithosphere characteristics.

For a better understanding of soil temporal variability, it is necessary to stress that the pedosphere is an immobile and patchy sphere, formed by many in situ processes. In contrast with the other spheres, the pedosphere can neither quickly intermix and circulate its own volume /as atmosphere/, nor quickly move laterally along land surface /as water solutions/, nor even avoid uncomfortable environmental changes /as biota/. So each soil, as an immovable and formed in situ body, is fated to endure all environmental changes at each site specific place and to transform itself according to climate, biota, and relief changes.

Based on the knowledge on the dynamics of soil properties gathered from soil monitoring stations and soil chronosequence investigations this basic scheme was improved, and a ranged sequence of soil properties was compiled according to their "characteristic times" or time changeabilities. The base of this grouping was the soil properties used for soil units and subunits diagnostics in the Revised Legend of the Soil Map of the World /FAO-UNESCO, 1988/ but many additional soil properties, and soil regimes were also evaluated and summarized in Table 4. As an attempt, the time changeability category numbers were given to all soil properties, listed in Tables 2 and 3.

Fluctuations and trend changes

Soil changes can be divided into 3 main groups:

1. Non-systematic /random/ changes

   These changes do not show a tendencious character, neither regular periodical /cyclic/ fluctuation nor trend changes, and occur in random spatial and time distribution. To this group belong:
   - numerous short-term changes /e.g. daily moisture content, depending on the rainfall distribution, surface runoff and evapotranspiration; daily soil temperature in the top layers, depending on the air temperature in the top layers, depending on the air temperature, sunshine /solar radiation/; aeration and composition of soil air, depending on moisture content, wind velocity; and actual microbial activity; etc.;
   - some mid-term changes /e.g. moisture regime under moderate climate; etc./;
   - a few long-term changes;
   - and most of the human-induced changes /under the influence of land use, agrotechnics, amelioration, soil moisture and nutrient control/.

   The modelling and forecast of non-systematic natural changes are rather difficult, sometimes almost impossible, or are limited only to a rough estimation with low probability. Further studies are necessary to find the primary reasons of these changes, rationally with the application of a comprehensive and accurate system-analysis. Local human-induced changes can be successfully predicted if the impact of the applied actions /technologies, etc./ are known on the basis of experimental results or various correlation analyses. The forecast of regional or global consequences needs careful territorial impact analysis.

2. Regular periodical /cyclic/ changes

   These changes are mostly related to the cyclic changes of pedogenic factors, as climate /regular, mainly seasonal variation of temperature, lighting, precipitation in some climatic zones/, water resources seasonal fluctuations of river levels and groundwater tables/ and vegetation /seasonal variation in biomass production, microbial acitivity, decomposition of organic matter, etc./.

   The frequency of regular changes shows great variations from hours to decades /or even longer periods/. Short-term periodicities are for instance the diurnal fluctuation of soil temperature, CO_2-content of soil air; mid-term periodicities are the seasonal changes in soil

Table 4. Time changeability of various soil characteristics

Time changeability categories and their characteristic time		Soil parameter	Properties and characteristics	Horizons and phases	Regimes
1	$<10^{-1}$ year	bulk density total porosity moisture content infiltration rate permeability composition of soil air nitrate content	compaction		aeration heat regime
2	10^{-1}-10^{0} year	total water capacity field capacity hydraulic conductivity pH nutrient status composition of soil solution	microbiota		microbial activity human-controlled plant nutrient regime
3	10^{0} -10^{1} year	wilting percentage soil acidity cation exchange capacity exchangeable cations ion composition of extracts	type of soil structure annual roots biota mezofauna litter fluvic gleyic properties stagnic slickensides	sulphruc horizon gelundic inundic salic phases yermic /fine earth properties only/	moisture natural fertility salinity-alkalinity permafrost
4	10^{1}- 10^{2} year	specific surface clay mineral association organic matter content	soil biota tree roots salic calcareous properties sodic vertic	histic /<20 cm/ ochric gypsic /podzols/ albic natric immature spodic gilgai placic phases sodic takyric	
5	10^{2} - 10^{3} year	primary mineral composition chemical composition of the mineral part	tree roots colour /yellowish, reddish/ iron concretions depth of soil cracking soft powdered lime indurated subsoil	histic mollic umbric calcic albic horizons natric cambic spodic nitic plinthite placic phase yermic /stone surfaces/	
6	$>10^{3}$ year	texture particle-size distribution SP, hy particle density	parent material depth abrupt textural change	argic oxic petrocalcic horizons petrogypsic duripan fragipan skeletic phases petroferric lithic rudic	

temperature moisture regime, groundwater table, organic matter and nutrient content under natural conditions; long-term fluctuations /year/s/ can be observed in moisture regime and groundwater conditions under the influence of long-term periodical changes in climate. Sometimes slight or moderate short-term fluctuations are combined with more expressive mid- or long-term periodicities; e.g. diurnal, monthly and seasonal fluctuation of soil temperature; daily, monthly, seasonal and yearly fluctuation of the groundwater table, etc.

The common feature of these changes is that after the cycle the registered value of the given parameter is the same or similar, as it was the initial value at the beginning of the period. Because of this reason the well-known cyclic changes can be forecasted with high or acceptable probability and accuracy, and modelling procedures can be efficiently used in their prognosis.

3. Trend changes

These changes show a definite tendency towards a certain general direction, which can be a straight or "spiral-like" decrease or increase. The general tendency is often combined with periodical fluctuations, e.g. the rise of the water table under irrigated conditions is combined with the natural seasonal fluctuation; the generally increasing or decreasing quantity of water soluble salts is combined with their seasonal migration in a salt-affected soil; the generally increasing or decreasing quantity of "available" plant nutrients due to proper or non-adequate nutrient supply is combined with the seasonal fluctuation of the "available" nutrient content of the soil; etc. Because the periodical fluctuations and the hardly separable irregular, and random changes are sometimes much higher than the low-rate but definite tendencious changes, the determination and exact characterization of trends require special evaluation procedures, accurate trend-analyses, including appropriate sampling-analysis-data processing-interpretation methods. Even in such cases the differentiation between trends and long-term cyclic fluctuation are sometimes questionable, like the registration of global climatic changes and their hydrologic, vegetation and soil consequencies.

Concerning trend changes in soil resources, their 3 main types can be distinguished:

A. Equilibrium trend. - The rates of the off-site displacement of soil material /erosion, accumulation and burial/ are less than the rates of the in situ processes /weathering, soil formation and evolution migration of soil constituents. Soil and soil cover remain on their site-specific places and can develop, evolve and change according to the temporal changeability of these in situ processes. Within this trend, many types of soil changes can be distinguished.
The major types are the following:
- a. The soil forms and develops in the stable, constant and usually natural environment, such as so-called soil self-development from the initial parent material to /quasi/equilibrium, climax, soil body, and state /status/.
- b. The soil "lives" in the changing environment, but these changes are so weak and/or so short-term that they can only change the soil /heat, gas, moisture/ regimes;

c. The soil exists in the strong and long-term evolving environment /climate, biota, hydrology, etc./, but without direct human impact on soil body and soil cover.

It is possible to identify several "lines" of such evolution:

- Erasing /or effacing/ soil evolution: the previous soil profile is erased /but without erosion/ and substituted for subsequent soil profiles.
- Developing soil evolution: the main features of the previous soil profile principally remain and are essentially developed and reinforced within the subsequent soil profile.
- Inheriting /succeeding/ soil evolution: the main features of previous soil profile are so stable /oxic and pan horizons, etc./ that they cannot be erased or developed, so the previous soil profiles are inherited by subsequent ones.

  In many cases the real soil evolution can include not only one "pure" line, but various combinations of erasing, developing and inheriting lines.

d. The soil evolves and quickly changes into naturally or, more often, anthropogenically changing environment with a direct changing of soil body by different forces /shallow and deep ploughing, fertilization, drainage, compacting by heavy machines, irrigation, terracing, etc./. In this type many anthropogenic forces can change the soil profile and soil solid-phase instantly. On the contrary, with the gradual natural soil evolution, such impact changes disturb the equilibrium between the soil and the environment. Soil, in this case, can be supported in such a nonequilibrium state /if the impact changes are repeated regularly/ or can reverse partly or completely to the equilibrium state /if the impacts are momentary or seldom/.

B. Denudational trend. - The rate of denudation /erosion/ is equal to or sometimes more than the rates of in situ processes /weathering, soil formation and evolution/. The main feature of this trend is that soils cannot reach their most developed and mature forms /profiles/ because soil formation is always weakened, rejuvenated from time to time. Within this trend two main types of soil changes can be distinguished:

a. The soil is eroded /by wind, by water erosion or by both/ completely; instead of soils, bare, massive or loose rocks are outcropped and different types of badlands are formed. The possibility of restoring /rehabilitating/ biota and soils on such land surfaces strongly depends on the relief condition, structure and composition of bared rocks and on the intensity of the subsequent erosion.

b. The soil is only partly eroded on the different depths of profile. Here several lines can be distinguished:

- The erosion removes and displaces only part of the humus horizons and the rest of this horizon is usually functioning within the soil and ecosystem. It is a loss of valuable soil constituents /humus, nutrients, etc./, but it is not a catastrophe.
- The erosion removes and displaces the whole topsoil which includes the most important fertile and biota comfortable horizons. The subsequent fate of biota and ecosystem depends on what kind of intrasoil and subsoil horizons occur on the land surface. These may be fertile B horizons developed in loess-chernozem profile, which is not so dangerous. It may be chemically toxic soil horizons /gleyic,

sodic, salic, sulfuric/ or physically unfavourable horizons as vertic, stony, pans. In both cases such soil changes are very harmful or even catastrophic for biota and ecosystem functioning, for terrain hydrology, etc.

The different types of denudational trend may combine with different types of environment condition and behavior. Two important combinations of this trend and environment can be distinguished:

- Denudation within the stable environment. After each denudational cycle, the new soil profile /body/ may form under the same stable environment. The results of each cycle of new soil formation will be strongly dependent not only on climatic and biotic conditions, but also on the character of the parent material which is exposed on the land surface by denudational processes. If this parent material remains the same as before denudation, the result of new soil formation will be the same as the previous eroded soil. If the parent material after denudation has changed /exposition on the land surface of various intrasoil horizons, or other geological layers of rocks/, the new soil formation under the same climate and biota may be essentially different from the old one due to changing of the parent material.
- Denudation within the naturally evolving and/or anthropogenically changing environment. In this case the formation of a new young soil after denudation differs from the old soil formation. This may be caused by new climate, biota, relief and parent material.

C. Accumulation trend. - The rate of off-site deposition and accumulation of any kind of solid-phase material on soil surface is equal to or sometimes more than the rates of weathering, soil formation and evolution. In this trend, soil also cannot reach its mature and climax forms /profiles/ because topsoil horizons are regularly or periodically enriched and the deposition of volcanic ash, desert dust or alluvial silt which usually has time to be "assimilated" by the topsoil and transformed by pedogenic processes, to soils completely buried by very intensive accumulation of solid-phase material /natural and/or anthropo-technogenic/, where a new young soil is formed on the deposited new parent material.

As with the denudational trend, the accumulative trend may develop both in a stable and evolving environment /natural and/or anthropogenic/. The results of these two kinds of development are the following:

a. reproduction of the same type of soil profiles after each burial /some andosols with buried multi-A and B horizons/, and
b. formation of different types of soil profiles within the stratigraphic column of loesses, reflecting the environment evolution during the Pleistocene period.

Reversibility of soil changes

The result of a soil change depends to a great extent on its reversibility, the general possibility and the possible rate and efficiency to turn back a certain process, with its consequences. Reversibility practically expresses the velocity ratio between a "primary" and a potential reverse change or process. If the "primary" process cannot be followed by a similar but reverse process, then the change is totally irreversible, e.g. the life of living organisms with their characteristic growing periods and development phases, their age and most of their life functions, or the use of fossil energy sources as fuel; etc. In any other case the process /the change/ is theoretically reversible, because under a certain time-interval the original initial situation can be re-established. However, if a soil change is much quicker than the potential reverse process it seems to be irreversible and can be taken as practically irreversible. In the contrary, if the potential reverse process is /or can be/ as quick as the "primary" process the change is totally reversible, e.g. most of the temperature changes, freezing-melting, wetting-drying phenomena, changes of the soil air; etc.

The reversibility of soil changes or soil processes depends to a great extent on the physico-geographical conditions /climate, relief, etc./ and on the characteristics of the local soil micro-environment /as the ratio and dynamics of the solid-liquid-gaseous phases, mineral and organic soil constituents, phase interactions, soil reaction, redox conditions, etc./ which determine the possibilities and rates of soil changes and their potential reverse processes. The direction, rate and intensity of soil formation; the development of diagnostic soil horizons, epipedons and their characteristic sequence: the soil profile, the mass and energy regimes within the soil; the probability and rate of various soil degradation processes all greatly depend on, and are sometimes determined by the reversibility of the contributing elementar soil processes. Depending on the local micro-environment the reversibility of the same process can be completely different. For instance: salt accumulation can be mostly reversible in the case of Na-, Cl-, SO_4-type salinization of light-textured sandy soils; and it can be nearly irreversible in the case of Na_2CO_3-, $NaHCO_3$-type salinization of heavy-textured, highly Na^+-saturated alkali soils with a high amount of clay, expanding clay-minerals and, consequently, a strong swelling-shrinkage character. The K^+ fixation can mostly be reversible in the case of light-textured soils with kaolinite-type clay-mineral associations; and it can be only slightly reversible in heavy-textured soils with smectite-type clay minerals.

In spite of the great variability in the reversibility of soil changes, generally it can be stated that:

- the processes result in changes in the stable or very slowly changing soil characteristics /e.g. soil profile with its characteristic layer-sequence or soil properties, mineralogical composition, particle-size distribution, etc./ as physical and chemical weathering, soil formation and profile development, soil erosion by water or wind, are practically irreversible or slightly reversible;
- the quick changes in the "labile" /non-stable/ soil properties /temperature, moisture content, composition of soil air, nitrate concentration, etc./ are usually reversible or mostly reversible.

Cyclic changes, regular periodical fluctuations /e.g. salt regime in natural salt-affected soils, wetting and drying under non-irrigated conditions, carbonate migration within chernozems, etc./ are mostly reversible or nearly reversible. In the contrary, trend-changes /e.g. formation of various diagnostic horizons, most of the soil degradation processes, solifluction, soil erosion by water or wind, etc./ are usually irreversible or slightly reversible. Non-systematic, random changes /as most of the human-induced soil alterations/ can be the consequences of both reversible and irreversible processes, or their combinations.

Some examples on the reversibility of soil processes and their consequences are summarized in Table 5.

Table 5. Reversibility of soil processes

Rever-sibility	Rate and velocity of change		Type of changes	Consequences		Example of soil samples	Actions required
	primary	reverse change					
R	q	q	quick changes	susceptibility of soils to acidification	but their control is simple and efficient	acidification of soils with low buffer capacity	permanent control and low dosage liming
				drought sensitivity		wetting and drying	frequent irrigation
R	S	S	stability	favourable conditions are stable, unfavourable changes are not probable		slow changes in the properties of fertile chernozems	maintenance of the given conditions
				unfavourable conditions are stable, their improvement is difficult, slow and complicated		slow changes in the unfavourable properties of solonetzes	radical soil reclamation
Ir	q	S	quick changes with low rate of reversibility	quick favourable changes /e.g. irreversible desalinization/		leaching of salts from light-textured soils and transport them away by horizontal drainage;	high efficiency of measures for the improvement of soil properties
				quick unfavourable changes, soil damages, serious soil degradations		intensive secondary salinization-alkalization due to unproper irrigation practices; water erosion	complex amelioration, including the prevention of further deteriorations
Ir	S	O or very S	slow, but practically irreversible changes: slow trend	tendencious, but slow favourable changes		maintenance of the given conditions	general soil development: formation of horizon and soil structure
				tendencious, but slow unfavourable changes		slow development of solonetzes with unfavourable properties	preventive measures; solonetz reclamation with low doses of amendments

R = reversible   Ir = irreversible   q = quick   S = slow   O = zero

Soil changes can be divided into 5 categories according to their reversibility:

1. Irreversible /practically irreversible/ changes, such as: physical and chemical weathering; turbations; solifluction; water and wind erosion; clay illuviation.
2. Slightly reversible changes, such as: development of diagnostic horizons and their characteristic sequence, the soil profile; decomposition of organic matter; destruction of clay minerals; salt accumulation in heavy-textured, highly alkaline and Na^+-saturated swelling clays.
3. Moderately reversible changes, such as: structure destruction, aggregate failure; leaching; P and K fixation in heavy-textured soils with smectite-type clay minerals and high exchangeable Al^{3+} content.
4. Mostly reversible changes, such as: wetting and drying; flocculation and dispersion soil compaction; dissolution and precipitation of carbonates; accumulation of salts in light-textured soils; cation exchange; P and K fixation and release in medium-textured soils.
5. Reversible changes, such as: soil temperature; redox conditions; changes in the composition of soil air.

The reversibility of soil changes has special significance in the case of human-induced soil processes. Various human activities may considerably change the local environmental conditions /soil reaction, aeration, redox conditions, moisture and nutrient status, microbial activity/ determining or strongly influencing the rate of soil changes, consequently the reversibility of different abiotic and biotic transport and transformation processes. These processes are discussed in detail in Chapter VI.

Shape of functional changes

When considering the above mentioned changes in soil features, especially as a basis for modeling, it must be realized that the changes are not necessarily simple linear or periodic functions, but can proceed over several pathways.

Frequently a change in one or several soil features will not be immediately observed when a change in the forcing factors occurs, but a certain threshold is needed for the change to start or to become expressed in the soil. A simple example can be given that erosion will not immediately occur when vegetation is changed or destroyed due to the effect of man or due to climatic change, but a certain number of other features /e.g. the destruction of surface structure/ needs to be evident first, before erosion becomes evident.

Once a certain process or change is initiated it may proceed in a simple linear function, but more frequently various feedbacks will be involved. Negative feedback is a common occurrence and indicates the effective resistance to change, i.e. a decreasing rate of change with time. Frequently it can be shown that the rate of a specific process is a function of its equilibrium state, i.e. the rate is decreasing when approaching the steady state /Fig. 8/. A certain number of processes can accelerate with time, showing a positive feedback /self enhancing/, as in an exponential function /Fig. 8/. Since an indefinite exponential function is of necessity impossible due to system constraints, the most frequent condition is a gradual change or transition to positive feedback producing a combined logistic curve of process change /Fig. 8/.

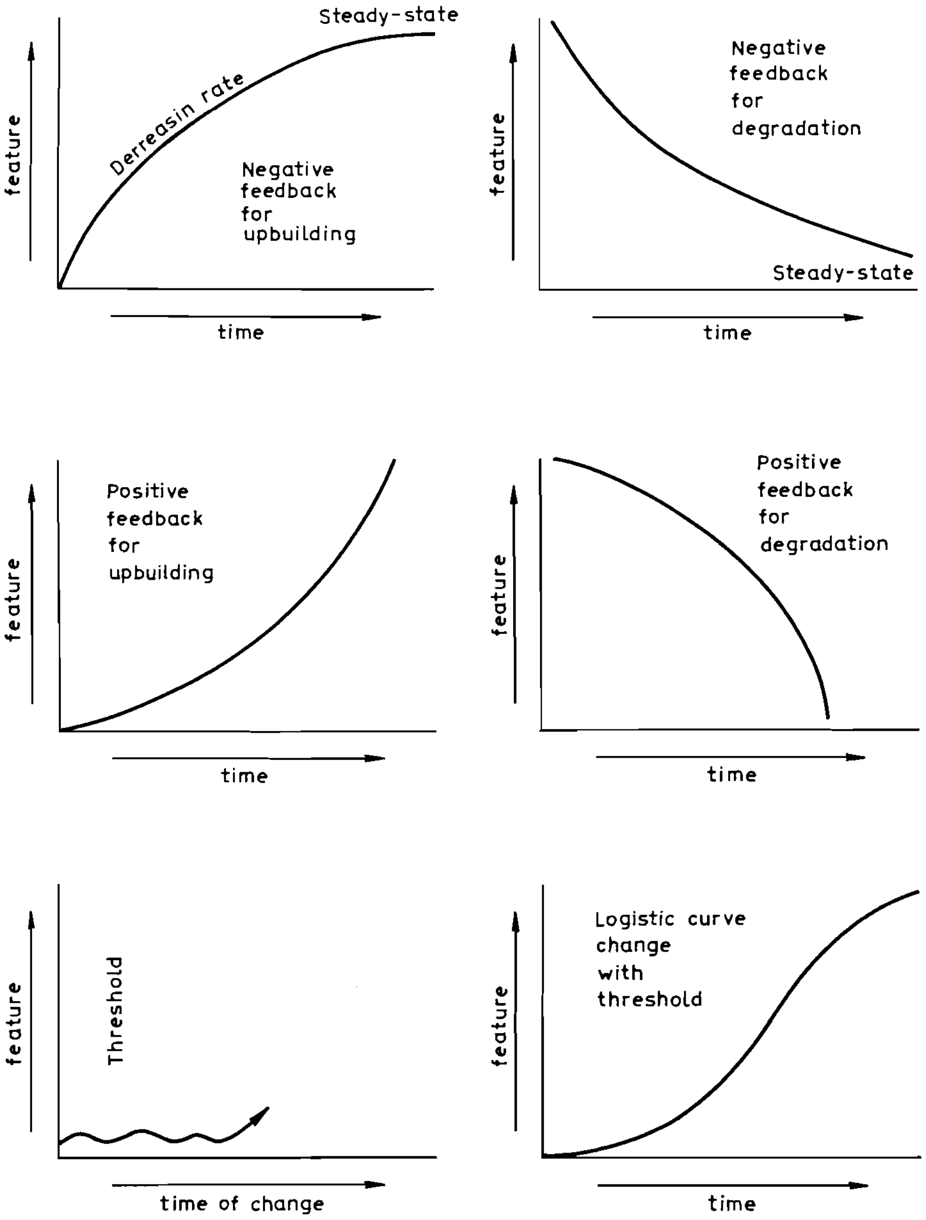

Figure 8. The shape of functional changes

Biomass transformation and soil changes

Before the evolutionary step into terrestrial biomass development and photosynthesis, with its release of gaseous molecular oxygen, not much more than half a billion years ago the atmosphere consisted of water vapour, NH_3 and CH_4. By photochemical reactions of the unshielded UV-radiation with water vapour escaping hydrogen and oxygen were produced; the latter of which readily underwent reactions with almost all environmental compounds available /such as: with NH_3 under formation of elemental N_2, with methane into CO_2 and H_2O/. Undoubtedly, CO_2, CH_4 and H_2O have already then exerted a greenhouse effect by absorbing more IR-radiation then releasing it back into space. Free oxygen in the atmosphere emerged as a product of CO_2-reduction and O_2 release by the photosynthetic process of biomass production. CO_2 occurred as a product of biomass recycling from the biocycle as well as by degassing of subduction zones and volcanogenic emissions, further also from the precipitation of $CaCO_3$ via the oxidation of $Ca(HCO_3)_2$ ($Ca(HCO_3)_2$ - $CaCO_3 + CO_2\uparrow + H_2O$) within the geochemical cycle. Particularly gymnosperms /since ca 350 million years/ and angiosperms /since the end of the Jurassic, ~ 120 million years ago/, as major representatives of the terrestrial florae contributed decisively to the oxygenation of our oxidating atmosphere, however also by their carbon turnover via respiration /biological recycling to stabilization of a CO_2-component in the atmosphere/. With N_2 and O_2, the major gases of the atmosphere only, the convective heat radiation back to space would have occurred unhindered. Only due to water vapour and CO_2, which have an absorption window for IR radiation, the surface temperature of the globe became - instead of -18°C - lifted to +15°C, whereby water vapour several times exceeded the contribution of the ca 200 ppm CO_2 at the end of the Pleistocene in its warming effect. With the beginning of human civilization a slow rise of CO_2 led to a CO_2 concentration of 280 ppm at the beginning of the industrialization, which has expanded to a source strength of 350 ppm CO_2 till the eighteenth century with a ~ 1% annual rise, which may lead to a temperature increase of some 2.5°C in the next 50 years. Partial blocking of absorption windows with rising trace gas concentration would interfere with a linear temperature increase and cannot be excluded. Also the ~50% absorption of CO_2 by the oceans follows an irregular pattern with higher rates in upwelling cold ocean currents, with lower net absorption in warm tropical water bodies or even El Nino-like effects with even CO_2 emissions. RAMANATHAN /1987/ estimates the GHE of the atmosphere to amount to 155 Watt/m^2, doubling of CO_2 would contribute 4 Watt/m^2. The effect of all trace gases since the beginning of industrialization is assessed to have added ~ 2.2 Watt/m^2, e.g. ~ 1.5% of the total GHE.

A possible eustatic sea level rise in consequence of the enhanced GHE and temperature with their effect on melting of polar ice caps is still uncertain /at least regarding its magnitude/. This ambiguity exists due to possible feedback effects between temperature rise, changing rainfall pattern /also possibly between present temperate rainy belt and polar high pressure area/ and changes of cloudiness whose real contribution to future GHE-caused changes or buffer effect is still quite poorly known for meaningful predictions. Till now the sea level rise is estimated to be 17 cm, and the predicted special temperature rise in the mesic, boreal and polar climate belts emphasizes its high actuality.

Both, temperature as well as sea level rise would have an intensive influence on the soil organic matter formation, -conservation and -recycling processes. Other organic matter constituents and decay products are: CH_4 with a 1.7 ppm concentration and 18 ppb annual concentration rise /~ 1.1%/ in the present atmosphere /RASMUSSEN and KHALIL, 1981/, with a relatively short mean residence time of ~ 10 years and a greenhouse promoting capacity compared with CO_2 of 20 to 32 on a mass flow basis /ENQUETE COMM., BUNDESTAG, 1988/; further N_2O with a 0.3 ppm atmospheric concentration, ~1 ppb, i.e.~ 0.3% annual concentration increase /RASMUSSEN and KHALIL, 1981/, with a long mean residence time of 150 years and a high greenhouse promoting capacity, compared with CO_2 of 150 to 240 /ENQUETE COMM., BUNDESTAG, 1988; CRUTZEN and MÜLLER, 1989/.

Carbon Pools

By the geochemical- and biocycle, carbon and organic matter have been trasported into different compartments. C has contributed to the basic H_2O/CO_2 GHE to make our planet habitable, it is the basic element for the nutritional cycle of plants and animals, it is till now the decisive element as energy source for the human civilization. In the following some important C-pool sizes are listed:

C in sediments /acc. to DEGENS, Geochemistry/ /for comparison, the whole pedosphere 14.1 bil ha, 1 m deep, bulk density 1.4 = 2 x 10^{14} t only/	3.9 x 10^{15} t
C in atmosphere	720 x 10^9 t
C in ocean	39 x 10^{12} t
C in soil organic matter, dead biomass ca.	2 x 10^9 t
C in soil living biomass	1 x 10^9 t
Annual photosynthetic yield, C-3, C-4, CAM /terrest./	115 x 10^9 t
Increment of C in soils /last ca 50 y, BERTRAM, 1986/	60 x 10^9 t
CO_2-C anthropogenic, annual addition from fossil fuels	5.5 x 10^9 t
from slash and burn /mainly trop. forests/	1.5 x 10^9 t

C-induced climate change in its effect on soil organic matter

Rising soil temperature means - according to the Arrhenius and Van t'Hoff law - higher reaction speed and, in case of the soil organic matter a faster turnover and a shift of properties in direction to the features observed in the arid and humid tropics. Some may be listed as typic.

- Humus forming in the tropics is usually mull or moder,
- Humus of tropical soils, smectitic, oxic or LAC is mostly difficult to extract because of its high polymer nature and intense metal - /clay/ - organic complexation, which alone can preserve it against the strong biological activity,
- Clay organic complexes are important. GREENLAND /1971/ and THENG /1979/ found in "lateritic red earth of 1.7% about 97.8% being incorporated in clay organic complexes. GILES /1960/ points to S, L, C and H types of adsorption isotherms of humic substances in such complexes.

- Mollisols, Alfisols, Ultisols and Inceptisols need organic matter badly for good soil structure formation and aggregation, Oxisols with hydrous oxides seem to depend less on organic matter in relation to structure.
- But organic matter is particularly important in LAC and Oxisols as a cation exchange compartment, since these soils /whose pH is mostly below the zero points of net charge of all constituent compartments with the exception of soil organic matter/ depend on organic matter widely for their cation exchange, since all other compartments are anion exchangers at soil pH-level. UEHARA /1982/ suggests measuring ΔpH as an indicator.
- Humic substances of the tropics are mostly higher in amino acid-N as well as amino-sugar-N than those from temperate climate soils /SOWDEN, 1977; SOWDEN et al., 1978/. Also, among the amino acids the basic ones are more strongly represented in the tropics and subtropics /STEVENSON, 1982/.

Climate change and organic matter recycling

Soil and plant organic matter can principally decompose in a soil environment by biotic, abiotic and photochemical mechanisms /SCHARPENSEEL et al., 1984/. In the temperate climate ~ 20% of plant residues /straw/ organic matter, which were previously uniformly ^{14}C-labelled, are left after 4 years. In the tropics the decomposition is accelerated by a factor of 4 to 6, as it was demonstrated by several authors under various ecological conditions regarding temperature and moisture /DALAL, 1979; ELLWARD and HAIDER, 1981; HAIDER, 1981; JENKINSON, 1971; JENKINSON and AYANABA, 1977; JENKINSON and RAYNER, 1977; JENKINSON et al., 1986; KRISHNAPPA and SHINDE, 1978; MANTLER et al., 1989; MARTIN et al., 1982; NEUE and SCHARPENSEEL, 1987; OBERLÄNDER and ROTH, 1980; PAUL and VAN VEEN, 1978; SAUERBECK and GONZALES, 1976/. JENKINSON and AYANABA worked in Nigeria, KRISHNAPPA and SHINDE in India, MANTLER et al. in India, NEUE and SCHARPENSEEL in the Philippines and Thailand, SAUERBECK and GONZALES in Costa Rica. MARTIN et al. /1982/ found a splitting factor CH_4/CO_2 of 2:1 in submerged soils of the Philippines. HOLZAPFEL-PSCHORN et al., /1985/ as well as WINCHESTER et al., /1988/ monitored the methane production, -emission and reoxidation in rice fields of S-Europe and China.

Effects on soils in climate zones, source strength, sink size

With rising temperature the organic matter of tundra-permafrost soils and of the rather poor and cold boreal soils should be engaged in intense organic recycling, this would produce another considerable release of CO_2. Part of this CO_2 release may be reincorporated in more intensely growing vegetation, whose root and straw remains may even slowly replace the original soil humus, which /primarily with rising temperature and maybe with the adjustment of the soil pH by liming when preparing it for agricultural production/, was vastly decomposed. The lack of sorption sites at clay surfaces or in clay interdomain cavities /AYLMORE and QUIRK, 1960; THENG, 1972; THENG and SCHARPENSEEL, 1975/ in case of Spodosols and Inceptisols in sandy Pleistocene sediments may render this process a lengthy one. Rough assessment of the medium/high latitude land area to be especially favoured by the predicted temperature rise /as a reminder: 4°C was the temperature drop only inducing a glaciation period/ and which is therefore facing accelerated soil organic matter decomposition as a CO_2

source, later with rising biomass production and neoformation of a more mull-like humus form as a sink, winds up to ~ 5 billion ha. The additional source strength during the initial phase of accelerated organic matter decomposition, supposed, the soils have in the upper 20 cm of the profile ~ 3% organic matter /1.5% C/, i.e. 90 t of organic matter /45 t of C/ per hectare, could be easily 0.5 t of C/ha, i.e. some additional 2.5 bil t of C /~ 6.8 bil t of CO_2/, which seems quite remarkable, even, if we tacitly imply, that some of it will immediately go into resynthesis of another humus form. The 2.5 bil t of C would be /2.5/7.0/ ~ 36 % of the annual release of CO_2-C from fossil fuel plus slash and burn.

In the tropics the lower absolute temperature rise /expected in the predictive models/ would also undoubtedly produce additional C-release by organic matter turnover. The nature of tropical humus as being mostly highly polymerised and fairly resistent against biotic decomposition may buffer to a certain extent. The additional organic matter decay in the tropics may also be much less important than the one in the higher latitudes, since it will probably be balanced to a certain extent by slowing organic matter turnover in the predictively expanding tropic-subtropical dry belt in the low, especially middle latitudes.

Chapter V

PALEOSOLS IN THE CONTEXT OF ENVIRONMENTAL CHANGES

In this chapter the significance of paleosols in the interpretation of environmental change will be discussed. As with other chapters a choice had to be made between the completeness and depth of the treatment and the requirements of brevity. We have thus confined our treatment to the essentials of paleosols definition and occurrence, with attention to the environment in which paleosols occur, their recognition and study, and especially the effect of climatic and environmental change on soil features with respect to the response time of change.

Some basic definitions

Paleosols, defined as soils which were formed in a landscape of the past, exhibit an excellent record of the past environmental conditions under which they were formed.

Of the five soil forming factors, climate frequently imparts to the soil over a period of time some very characteristic features, depending on its position in the landscape and the parent material. Soils generally respond to climate or climatic change in conjunction with the vegetation and frequently respond slower than the vegetation, thus integrating the environmental conditions over a certain, longer period of time. They are probably a more true record of the regional climate than pollen sequences, which seem to show considerable variation over a short time range.

Based on their position in the landscape, buried, non-buried and exhumed paleosols can be distinguished. Buried and exhumed /previously buried/ paleosols may have been subject to additional diagenetic changes following their burial, which need to be separated from those of the original pedogenesis. An important maxim in the study of paleosols is that they have to be studied by the same methods as modern soils /YAALON, 1971/. On the basis of their soil profile section, simple /complete or isolated/ profiles and compound /complex or welded/ profiles can be distinguished. In the latter case more than one soil forming period and/or sedimentation of new material, when it is less than the depth of pedogenesis, are the cause of the superposition. Such sections are frequently difficult to recognize and interpret.

Environments in which paleosols are known

Whereas non-buried paleosols can theoretically occur in all landscapes and environmental conditions, depending on the degree of change we wish to recognize before a surficial soil is recognized as paleosol /see further explanation below/, buried paleosols are to be found in a number of well-defined environments, as follows /see also RETALLACK /1981/ and WRIGHT /1986/:

A. Buried paleosols can be encountered in:
   - Glacial tills
   - Eolian loess and eolian cover sands
   - Fluvial terraces
   - Alluvial fans
   - Landslide debris and colluvium
   - Volcanic ash
   - Basalt flows
   - Coastal sands
   - Lake deposits
   - Marine transgressions
   - Peats and coal deposits
   - Archaeological deposits

B. Non-buried paleosols are relict surfaces following change:
   Occur in all environments depending on persistence and degree of change.

C. Exhumed paleosols:
   Occur where covering of buried paleosol was eroded.

Burial by glacial tills has produced some well-studied paleosols, frequently used as stratigraphic markers for the dating of Quaternary glacial events. They mostly represent the warmer and relatively shorter interglacial or interstadial periods. Eolian loess and eolian cover sands are a widespread and most significant burial agent. Because a more complete profile sequence is frequently preserved, the buried paleosols in the long continuous sequences of loesses in China, America and Europe are probably the best ones for climatic interpretations and long distance correlation on the continents and also with the marine record /CATT, 1988/, especially where a good dating exists of the duration of the soil forming period by accurate dating of the sediments above and below the paleosol. On the other hand, when the rate of loess deposition between soil forming periods was small, the paleosols frequently are complex or compound and may exhibit in their specific features more than one soil forming interval. In desert fringe regions, where loess deposition was not interrupted by the spread of glaciers, this condition - reflecting a gradual rather than abrupt change in environmental conditions - seems to be the common feature..

Paleosols buried by fluvial sediments in river terraces or alluvial fans are a common feature in semi-arid regions. Frequently, due to the natural development of the river system or the fan, they need not necessarily indicate a significant change of climate, but rather some definite fluctuations in the sediment producing catchment area and frequently also tectonic activity. They have been extensively used for the reconstruction of climatic conditions in many regions, especially in pre-Quaternary sediments. Paleosols buried by landslide or colluvium are of more local extent and essentially indicate a drastic or catastrophic event of local extent. The buried paleosol thus can be used for the reconstruction of the landscape before the event in question and may frequently herald more extensive regional climatic changes. Since vegetation destruction by drought, fire or man is often the first sign of climatic change, resulting in greater erosion rate and colluviation on footslopes, such paleosols are common, especially in subtropical and Mediterranean regions with a seasonal moisture regime.

Paleosols buried by volcanic ash or basaltic flow are also quite common, but do not necessarily indicate a regional change in climate. The possible effects of the hot basalt or chemical interaction with the ash need to be duly considered in the interpretation of paleosol of such soil landscapes. Some of the landscapes enable the reconstruction of the catenary soil sequence in the buried landscape and also provide a good estimation of the duration of soil formation if deposits above and below the respective paleosol can be dated.

Coastal sands, lake deposits and marine deposits during sea transgressions are another set of sediments with paleosol occurrence in different environments, especially where changes in sea level are the cause of the change in environmental condition. It is thus not restricted to a specific climate range. Coastal deposits or lakes frequently cover peats, which of course are also a type of paleosols. In a similar way coal deposits and their associated underclays /kaolinite and illite mostly/ are characteristic paleosols in a thick and longstanding forest vegetation, subsequently covered by other sediments. They are thus the major indicator of the environmental conditions during these geological periods.

Finally, paleosols covered by man-made and archeological deposits need to be included, which have become one of the more important objects of detailed examination on archeological sites, for the interpretation of environments under which man lived and worked /HOLIDAY, 1989/. The study of such paleosols may be especially useful in interpreting the rate of change and over a relatively short time period, provided good dating of the site and its various deposits is available. This, of course, is different from the study of the anthropogenic effects on the soil cover, which are discussed in Chapter VI. There the more extensive regional changes are outlined when due to man, as a result of cultivation, grazing, irrigation or drainage are carried out on a large scale. But it brings our attention, by analogy, to the problem when can or should a significant change in the soil cover be recognized as producing a non-buried paleosol, i.e. a soil formed in a landscape of the past or merely metapedogenesis /YAALON and YARON, 1966/.

Since there are no time limitations on the term "past", soils covered by colluvium, landslide or ash are paleosols, irrespective when it happened. Though not formally defined as such, a 10 to 20 cm thickness of covering is probably the minimum for preserving the paleosol. Where the cover is thinner than that, the covering material frequently becomes mixed with the A-horizon of the soil and thus incorporated with the current soil forming process, but not necessarily changing its direction. Where the direction of the soil forming process has been changed, we may speak of a polygenetic, mixed or complex surface soil, in analogy with the complex or compound paleosols.

Non-buried paleosols or steady state disturbance

A large part of Australia is covered by various crusts and relicts of silcrete or ferricrete, which obviously were not formed in the present dry climate prevailing over most of the continent. They formed in the long distance past when the continent was subject to much stronger leaching over an extended period of time. The current dry climate preserved these ancient formations, which never became buried and thus represent typical relief or non-buried paleosols. In other regions the climatic or environmental change may have been less drastic. So the question inevitably arises how much change is required in a modern soil to be recognized as paleosols?

Soil development is a relatively slow and complex process. Most soils take a long time to reach maturity, which can be defined as a steady state condition in which processes of weathering and new soil material addition are balanced by the inevitable leaching and surficial erosion, or when the terminal stage in the development of irreversible features such as duricrusts of calcrete, silcrete or ferricrete origin is searched.

When speaking of steady state it is best to distinguish between features which approach steady state relatively rapidly, such as the accumulation of organic matter in the surface horizon, within one or two hundred years only, and features approaching the steady state slowly, over a period of thousands of years, such as clay accumulation and its redistribution in the profile. Except for some features which approach the terminal stage and are irreversible, a large number of soil features are reversible, as required by the concept of steady state, for example the accumulation or leaching of salts or of carbonates.

It has been postulated that those features which approach the steady state condition fairly rapidly will also be subject to a relatively rapid reversal or change when the conditions are changed, and those features which approach the steady state slowly, will be resistant to change. Duricrusts and other features which exhibit irreversible changes will be most resistant to change /YAALON, 1971/. Numerous studies have confirmed this postulate, especially with regard to organic matter accumulation or destruction, salinization and desalinization, carbonate accumulation and leaching, pH changes, clay translocation, etc. The grouping of these features into classes according to their ease or resistance to change is thus one of the guiding principles in recognizing and interpreting paleosols /Table 6/.

The above concept is closely related to the concepts of resistance to change or response time of soils, which is so important in recognizing the effect of global change to which the world is being subjected now. The question really is how much soil change is needed for the recognition of the effect in non-buried palesols. There are those who have postulated that steady state conditions in soil formation do not exist and are merely a figment of a theory, because the soil is a dynamic system continuously subject to the effect of environmental factors, which themselves are not

Table 6 A grouping of soils according to the relative persistence of soil horizons and features. /After YAALON, 1971/.

Easily altered	Relatively persistent	Persistent
Mollic epipedon	Histic epipedon	Oxic horizon
Ochric epipedon	Umbric epipedon	Placic horizon
Salic horizon	Albic horizon	Argillic horizon
Gypsic horizon	Cambric horizon	Natric horizon
Mottles	Argillic horizon	Petrocalcic horizon
	Spodic horizon	Plinthite
	Calcic horizon	Duripan
	Fragipan	

steady but in a dynamic flux, frequently subject to cyclic variations over a short or long time scale. As an example, the soil is always either cooling or warming in response to the cyclic input of solar energy following diurnal, seasonal or even multiannual cycles of variable length. The same kind of thought can be applied to all other features of the soil. For example the soil is for ever either becoming imperceptibly thicker or shallower, depending on whether the process of rock weathering at depth prevails over the process of surficial erosion /JOHNSON, 1985/. Any notion of steady state thickness must be according to this concept only short-lived, during the transition from the stronger erosion mode to that of the stronger weathering mode. If steady state is a myth then, by extension, all soils are polygenetic and thus essentially paleosols.

While the continuous processes in soil dynamics and their quantification are extremely important in recognizing the response of soil to change and the response time for various features, it would be unwise to recognize all soils when subject to minor changes, as paleosols. Cultivation of the original natural soil has gradually decreased the organic matter content and biomass carbon in the soil environment and fertilization has frequently changed rather drastically the cation population or pH of the clay. But it would be unwise to call such new conditions as paleosols, unless the overall soil forming process and its direction have been changed.

Thus, as a rule, it should be recognized that most soils covering the present landscape have been subject to minor fluctuations in the present environment, which formed them, and are thus strictly, to a smaller and larger extent, 'polygenetic'. But even if these essentially normal fluctuations of the environmental factors affect the soils, whether caused by man or nature, e. g. the effect of prolonged droughts, they should not be recognized as paleosols unless the direction of the soil formation process has been changed.

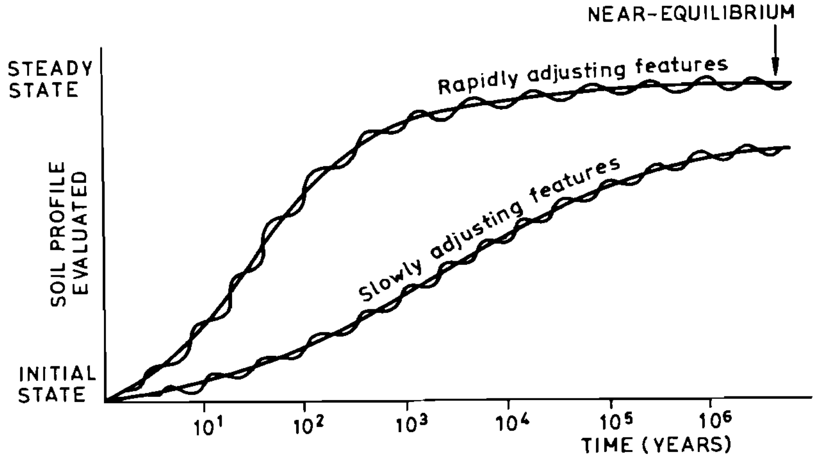

Figure 9. A diagramatic representation of the time taken to achieve steady state in generalized soil properties after the initiations of soil development. The response of various soil properties to climate change will range between these two extremes /YAALON, 1971/

All soils possess a certain inherent resistance to change, the negative feedback factor, and require mostly a certain level of threshold before change becomes evident easily. A few properties are subject to the positive, enhancing feedback factor, at least for a certain time period. Chronosequences of soil features, measuring the change in soil properties are thus rarely linear, but frequently follow a logistic or log-normal trend /Fig. 9/. It is necessary to know their shape and the rate of change or response time for as many features as possible, in order to predict the changes which we might witness as the result of global climatic change.

The study of paleosols is thus not only one of the best means to reconstruct past environmental conditions but is also needed for the prediction of the resistance to change and response time of various soil features when subject to environmental change.

Chapter VI

ANTHROPOGENIC EFFECTS ON SOILS

With the appearance of the human race on the Earth even the changes of the environment became different. Due to human activities the natural processes affected by biotic and abiotic factors accelerated and several others, which were unknown or minimal before, developed.

At the very beginning, when mankind was not yet widespread on the continents, environmental changes did not differ from those preceding human interference. Later, however, when the number of human beings increased and great parts of the continents were already populated, the effects of their activities became extended and detrimental, and the natural environment began to alter at a much more accelerated rate.

However, even in the early periods of human history the cutting of woods, hunting, application of fire, etc. caused alterations which were intensified by the introduction of agriculture. Later, due to the development of technics, on the one side, and the multiplication of people on the other, these changes extended increasingly both in space and in respect of the intensity of the effects.

Both favourable and unfavourable changes took place, but we must realize that when we qualify them as such it is always on a basis of benefit or harm from the point of view of human life.

All this is fully valid when we speak of the global soil cover and of global soil changes.

A short historical review

As long as the primitive man had not cultivated land but only collected his food and fuel he only caused minor changes in the soil forming processes; changes, that differed not too much from the effects made by animals. With the introduction of agriculture it became possible to gain more food from the soil than ever before. This result can even be qualified as advantageous. However, agricultural production often exhausted the soil to such an extent that the population had to move to a virgin land, and with this, shifting agriculture was born.

Man became a powerful geologic force on the Earth, changing its geochemical and biological cycles, the composition of global atmosphere and hydrosphere, the structure of the lithosphere, regulating the mechanisms, of geospheric interactions /VERNADSKY, 1965/. Major changes have gradually occurred in the global functions of the pedosphere.

The time-scale of the above environmental changes caused by man, including anthropogenic soil changes, is of logarithmic character in full conformity with the time-scale of the development of mankind:

- 1-2 million years of very gradual changes due to very weak and sparse human impact upon the environment during the prehistoric times of the Paleolithic and the Neolithic;

- about the last 10 thousand years of agricultural civilization embracing /or expanding/ not only tropical but also temperate and boreal regions;

- about the last 300 years of colonization of continents; agricultural development of steppes, prairies, savannas: general expansion of agriculture, particularly of market agriculture;

- about the last 150 years of agricultural chemistry - development and expansion;

- about the last 50 years of technological advance on the basis of scientific-technical progress of recent times.

In arid and semi-arid regions irrigation had to be introduced at the very beginning of agriculture as no production was possible otherwise. The primitive methods of irrigation resulted in marked changes in the salt balance of the given territory without the perpetrators realizing that they had triggered such processes. It is a fact of history that in Mesopotamia, South- and Central America, South-East Asia and other regions vast deserts developed in the places of fertile lands due to secondary salinization following in the wake of irrigation. On the other hand, it is also true that in some lucky river valleys and lowlands, where secondary salinization, alkalization, or waterlogging had not occurred, irrigation mainly resulted in useful alterations of soil fertility which underlay a regular supply of food for the increasing population and of fodder for animals.

Even in ancient times forests were cut down in many parts of the world, ancient overgrazing, subsequent erosion and desertification in arid and semi-arid regions, resulting in the intensification of erosion processes and the loss of tremendous amounts of fertile soils.

Man as custodian, conserver and steward of soils

The influences man had on soil changes from the very beginning can be subdivided into two groups.
I. Indirect effects of human activity on the soil.
II. Direct influence of human activity on the soil.

I. Indirect effects include those which affect the soil through other media. They are as follows:

1. a/ Changes of atmosphere, including changes of the hydrothermical macroclimate system, changes of microclimate, changes of the direction and intensity of winds /e.g. through planting forest belts or deforestation/;

   b/ changes in the chemical composition of the atmosphere /CO_2, CH_4, SO_x, NO_x radioactive fission products and others/;

c/ appearance of suspended matters in the air /both the natural /aeolian dust/ and anthropogenic /technogenic aerozols, carbonates, silicates, sulfites and others/.

2. Changes through the hydrosphere. The human effect results changes in the hydrosphere of both continents and oceans; like
   a/ changes in the sea level /including the change in the intensity of tides/;
   b/ changes in the depth and chemical composition of the groundwater;
   c/ changes in the fresh water regime on the continents /rivers and lakes/.

3. Changes in the lithosphere, including
   a/ the changes in oxidation-reduction conditions in the upper layers of the earth's crust /causing, e.g. gley formation or oxidation/;
   b/ changes in the salt balance, salt migration and salt accumulation;
   c/ accumulation of heavy metals and other substances caused by industrial emissions.

4. Changes through the alteration of the biota:
   a/ changes of the natural plant cover, including deforestation, overgrazing, etc.
   b/ burning of bushes, forests, savannas and others;
   c/ overloading the carrying capacity of plants; overexploitation of the biosphere through crops, animals and others which result in adverse effects on the biogeochemical processes.

II. The direct influence of human activities on the soil is mainly considered to mean the effects of machinery, tillage and ploughing, of the application of chemicals, of contamination and, last but not least, of irrigation on soils. Such effects result in direct short-term or long-term changes and they are the major agents in all contemporary soil changes, including those which lead to the deterioration or degradation of land and soil. Because these processes represent the most significant transitions going on at present they will be described after a short review of the present situation.

The present situation

As an integrated effect of man on soils the present global situation has formed mainly as a result of the development of industry and agriculture during the last one and a half centuries together with the accelerated increase of world population.

In the course of history the territory of cultivated land increased for a long time in most areas and this process was only interrupted by natural or social disasters when the population diminished or disappeared.

In the last centuries in most of the developed countries in Europe and North-America the acreage of arable land diminished simultaneously with an increase of the total production. However, in many other areas still new territories are put into cultivation /particularly in developing countries/.

The cardinal problem is the characterization and measurement of the integrated effect of human influence on soils and soil productivity. There are lots of data and information available on the consequent soil changes but even more presumptions, errors and illusions, even slogans which, on the one hand, neglect the hazard of adverse alterations of the world soil cover and its productivity and, on the other hand overestimate /sometimes hysterically/ this phenomenon. This is the reason why we have to study both the beneficial and the adverse effects of the present human activities on the world's soil cover sine ira et studio.

Table 7. Agricultural land per capita in Germany

Year	Hectare per capita
1883	0.78
1937	0.35
1950	0.29
1989	0.20

Table 8. Number of people fed by one US farmer

Year	Total	At home	Abroad
1820	4.1	3.8	0.3
1900	6.9	5.2	1.7
1920	8.3	6.9	1.4
1940	10.7	10.3	0.4
1950	15.5	13.8	1.7
1960	25.8	22.3	3.5
1970	47.1	39.9	7.2
1977	59.8	42.8	17.0
1989	65.0	47.0	19.0

As a matter of fact it is not easy to measure soil fertility precisely. It is somewhat easier to characterize soil productivity by the weight of harvested yields. In this respect the productivity of the soils of the world has permanently increased practically without interruption during the whole history of mankind and this growth has particularly accelerated in the last two centuries mainly in the developed countries. At the same time in these countries the percentage of population engaged in agriculture has sharply decreased, as it is shown in Tables 7 and 8.

The tables clearly demonstrate that not only a unit of cultivated land can yield much more products than before but also one person engaged in agriculture can feed much more people than 100 or 50 years earlier.

The situation is somewhat different, e.g. in the USSR according to data by V. KOVDA and Y. PACHEPSKY, reporting that 25 years ago 1.2 hectares per capita was the proportion of arable land and population which became 0.8 ha by now. Such phenomenon is common in numerous developed countries. In this case however the authors note that yields had not increased but also dropped.

Similar examples can be found in numerous other countries or areas, although in some of them the poorer yields are due to different reasons. Among these reasons, besides unfavourable natural conditions, the low level of industry and technology, poor chemization and mechanization, poor planning and organization, social disturbances and others can be mentioned.

Table 9. Land area and use - Mha

	Land	Cropland	Pasture	Forest, woods	Wilderness
World	13,079	1,475	3,160	4,082	5,089
Africa	2,965	184	782	695	918
North and Central America	2,139	274	362	660	901
South America	1,753	139	451	928	422
Asia	2,679	455	644	528	372
Europe	473	140	85	155	18
USSR	2,227	232	373	929	875
Oceania	843	49	455	158	260

Table 10. World increase in cropland and yields, 1964-1985

	% change in cropland	% change in yield	
		Cereals	Roots/tubers
Africa	13.5	13	22
Asia	4.1	77	58
North and Central America	7.8	44	23
South America	34.6	42	-1
Europe	10.5	76	19
USSR	1.3	35	13
Oceania	23.5	25	13
World	8.9	58	21

According to the publication "World Resources, 1988-1989" data on the land area and use of the World are given in Table 9. The table shows that croplands cover only a small part of the total territory of the continents. In Table 10 the world increase in cropland and yields during the last 20 years is demonstrated. The data illustrate that on all continents an increase in production can be observed, however, the rate of this increase is very different. Nevertheless, nearly a 10% increase of the world's cropland production was reached during the last two decades.

Principally the application of up-to-date machinery, fertilizers and other chemicals as well as modern technology and, last but not least, irrigation have made it possible to sustain and even increase the production of soils in most areas. As an example of such processes, in Table 11 the increase of irrigated land in the world during the last two centuries is demonstrated. From Table 11 it can be inferred that during thousands of years irrigation developed rather slowly, while in the last century its development has accelerated and further extension of irrigated areas can be anticipated. However, this development has been associated with adverse effects, too, as it will be described later.

Table 11. Development of irrigation in the world

Year	Irrigated land /million ha/
1800	8
1900	48
1949	92
1959	149
1989	200

Throughout his activity, man not only tried to collect and produce more food and other commodities from the soil and at this time acted sometimes as conservator and care-taker of this important natural resource, but very often became the destroyer of soils and of soil fertility.

There are unnumberable ancient and modern methods which have been practised by man during his activity for improving the soil, to sustain and even increase its fertility. We can only quote examples here of such activities, without going into details of their history and technology.

Terracing, stone clearing, strip cropping and bunding belong to very old methods of soil conservation, while empoldering, silt accretion, dune stabilization required more advanced technology. Large areas have been put into production as a result of such methods, i.e. in the polders of the Netherlands and some areas of South-East Asia.

Irrigation and drainage represent a specific system in agricultural production, with both positive and negative effects /as it is discussed in other places in this chapter/.

One of the main efforts of agricultural production is to sustain and increase soil productivity by the application of organic and mineral fertilizers and compost, which recently represent a specific part of agricultural chemistry and soil science.

The application of chemical amendments also has been and remains a very important method for the reclamation of land. The liming of acid soils and application of gypsum in alkali soils should be particularly mentioned.

To combat erosion, both in the past and at the present time, numerous systems of reclamation and prevention have been elaborated and nowadays land fixation, structure improvement are practised partly with the application of modern chemical products.

Advanced agricultural machinery makes possible a more effective deep ploughing, the mixing of soil horizons and other methods in order to increase the productivity of soils.

Degradation of soils resulted by natural and mainly man-made effects and soil degradation affected by the same agents can be observed in many areas on the continents concurrently and it is site-specific whether one or other prevails. That is the reason why we have to study thoroughly both beneficial and adverse effects, when evaluating the anthropogenic effects on soils, avoiding extreme opinions.

It would be a great mistake to conclude from the above facts that adverse changes in the world's soil cover do not develop or they only develop in a small measure. On the contrary; we have to face both a diminishing in the territory of productive soils and the different processes harmful to soil productivity and environment.

We still have great resources on our globe. Table 12 shows the estimated total land area and the potential resources according to broad soil groups. Evidently, the percentage of potential arable land is distributed unevenly between the different soil types /Table 12/.

At the same time, we are confronted with severe limitations for agriculture on all continents, which are resulted by different processes. The data of Table 13 clearly show that factors limiting production do not exist only on about a tenth of the total soil surface of the Earth.

Reduction of global soil resources

Global soil resources diminish mainly due to two reasons:

1. Reduction of arable land by conversion to other purposes.
2. Reduction of arable land by adverse processes.

1. Reduction of arable land by conversion to other purposes

The absolute decrease of agri- and sylvicultural lands is caused by two processes:

a/ the conversion of rural land to urban and industrial development and transportation purposes, and

b/ the drastic disturbances of land by strip mining, waterlogging, and dam construction, etc.

Land conversion - As a rule, the reduction of fertile land has occurred parallel with and as a result of the modernization of the way of life and the advance of technology. In the United States more than 2 million hectares of rural land are converted annually to urban and transportation uses and to water bodies. In the FRG more than 2.5% of all agricultural land has been lost in the same way in the last decades.

In Figure 10 the changes of the agricultural territory in Czechoslovakia are demonstrated. The figure shows a slow decrease of acreage per capita of agricultural land /HRASKO, 1987, 1988/.

In Canada between 1981 and 1986 55,210 hectares of agri- and sylvicultural land were converted to urbanization and a great part was taken from agricultural production.

Table 12. Estimated total land area and potential arable land by broad soil groups

Broad soil group	Total area	Potential arable land	Potential arable as % of total area	Potential arable as % of group
	in million hectares			
Tundra	517	0	0	0
Desert soils	2,180	430	3.3	20.7
Chernozems and brunizems	822	450	3.5	54.5
Noncalcic brown soils	291	110	0.8	37.8
Podzols	1.920	300	2.4	15.6
Red-yellow podzolic soils	388	130	1.0	34.2
Latosolic soils	2,500	1,050	8.1	42.0
Grumusols and terra rossas	325	180	1.3	55.4
Brown forest soils and rendzinas	101	30	0.2	3.0
Andosoils	24	10	0.1	41.7
Lithosols	2,722	80	0.6	2.9
Regosols	763	70	0.5	9.2
Alluvial soils	595	350	2.4	58.8
Total:	13,150	3,190	24.2	

Table 13. Major soil-related limitations for agriculture in % of total land area

	Drought	Soil compaction	Shallow soil	Excess water	Permafrost	None of these limitations
Europe	8	33	12	8	3	36
Central America	32	16	17	10	-	25
North America	20	22	10	10	16	22
South Asia	43	5	23	11	-	18
Africa	44	18	13	9	-	16
South America	17	47	11	10	-	15
Australia	55	6	8	16	-	15
Southeast Asia	2	59	6	19	-	14
North and Central Asia	17	9	38	13	13	10
World average	28	23	22	10	6	11

from CERES, 1978

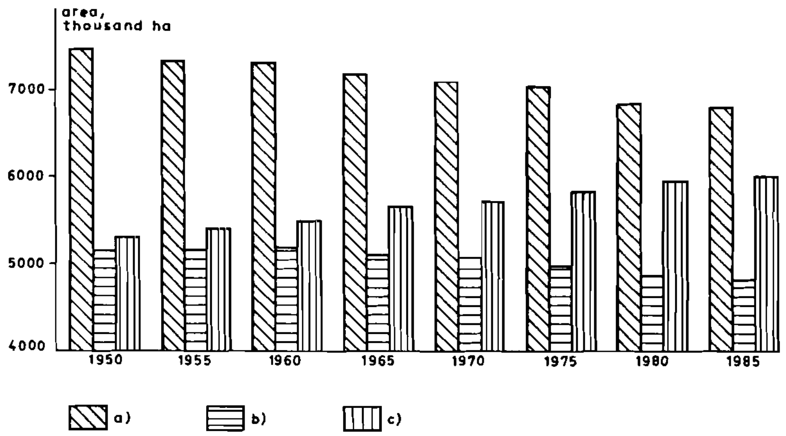

Figure 10. Soil resources in Czechoslovakia: a/ agroland; b/ arable land; c/ others.

Even in developing countries, such as China, factories are being built on lands that have yielded two harvests annually for a long time.

Unfortunately, putting rural land to other uses is practically an irreversible process and means a permanent loss of fertile soils and renewable resources. Studies must be conducted to determine why it happens ever so often to the best soils.

If this practice of regularly encroaching upon rural land continues, new areas available for future cultivation on a world-wide scale will be rather limited. Everywhere the best soils are being affected and the virgin land left consists mainly of marginal or low-fertility soils. The trend is worrysome as it threatens the possibility of attaining the expected and predicted higher yields in the forthcoming decades.

In a number of countries strict measures have been taken to limit or prohibit the conversion of rural land to other purposes, however they are far from being sufficient and effective in aborting the continuous process of converting fertile soils.

Land disturbances - Drastic disturbances of land are resulting the reduction of soil fertility to the point where agricultural utilization is no longer possible. The main culprit here is mining, although municipal sewage disposal, oil exploitation, stone quarries, sand and gravel pits, etc. have also played a significant role.

In the United States more than 1.5 million hectares of fertile land have been destroyed by mining in the last 40 years, and only about one third of this territory has been partly or completely reclaimed. In many European countries the situation is even worse.

As industry and technology continue to develop year by year, more and more agricultural land will be destroyed. In the United States, for example, it is predicted that by 1990 nearly 50,000 hectares of good soil will have been ruined just by the surface mining of coal. This is more than twice as much as the land that had been destroyed by the same activity until 1975.

The reclamation of increasing territories in some countries cannot offset the destruction of soils in other areas of the same country, not to mention other countries. Sometimes land reclamation efforts are reminiscent of Sisiphus'task. It is important to speed up reclamation projects applying proper policy and appropriate methods, but it is also vital to diminish the yearly losses of fertile land caused by drastic disturbances.

The conversion and disturbance of arable land on a world-wide scale diminish the cultivated areas on our globe annually by a territory larger than all the acreage under cultivation in the FRG and France together. Optimistic predictions of increasing arable land may go up in smoke if the present rate of reduction does not drop steeply and very soon. Unfortunately the world trend of submerging fertile earth under asphalt is on the increase.

Garbage and sludge represent an ever-growing problem due to their negative influence on the soil. During history it has been believed that soils are capable of decomposing all garbages and other by-products. This is true to a certain limit. However, nowadays the quantity of garbage and sludge increased to such an extent that in many places they have accumulated and result the reduction of soils and soil fertility, particularly when - and that is not an exclusion - toxic substances occur in the garbage.

2. Reduction of arable land by adverse processes

There are numerous anthropogenic processes which greatly reduce the fertility of soils. In case of the expansion of such processes fertility may be reduced to nil and the land lost for production. These adverse processes will be characterized only very briefly.

Soil erosion - Estimates of the loss of fertile soils affected by the processes of erosion are available in abundance. While the accuracy of these estimates varies greatly, it is beyond doubt that erosion causes tremendous damage and that the hazard for the future is even more serious. It appears that the amount of soil nutrient compounds removed annually by erosion is roughly equal to the amount of commercial fertilizers used all over the world. America's agricultural lands lose 4.8 billion tons of topsoil yearly to erosion, enough to cover all the cropland of Maine, New Hampshire, Vermont, Connecticut and Massachusetts with one foot of earth. In an average year, one-third of all cropland suffers from erosion beyond the "tolerable rate", the maximum level at which the soil's fertility can be maintained. The productive equivalent of more than 3 million acres of farmland are lost every year because of erosion. Iowa loses almost 10 tons of topsoil per acre each year. For every pound of wheat harvested in eastern Washington, 20 pounds of soil are lost. In Texas wind erosion alone blows 15 tons of soil yearly from each acre of cropland. In the last 200 years, erosion has destroyed at least one-third of the USA's topsoil.

Besides the losses of plant nutrients, a tremendous amount of organic soil material is lost as a consequence of erosion. The reduction in the humus contents of the soil is detrimental to soil structure, soil-buffering capacity, soil biology, etc. and in general, it contributes to the deterioration of the renewability of soil fertility.

Erosion has always existed, under natural conditions, too, but human activities, mainly deforestation, agriculture, grazing, etc. have aggravated its extent and increased the territories affected.

Soil erosion assumes disastrous proportions in many developing countries. Fig. 11 shows an example from Tanzania of the loss of both soil and water caused by erosion. As Fig. 11 demonstrates, as soon as a soil is brought into cultivation the erosion hazard increases.

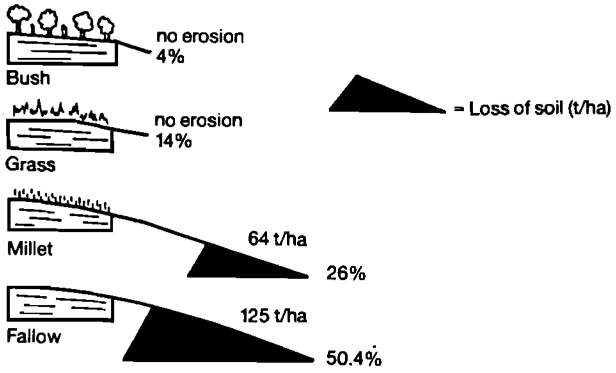

Figure 11. Eroded soil /t/ha/ and precipitation water loss /%/ in Tanzania

Secondary salinization, alkalization and waterlogging in irrigated areas - About 200,000 hectares are under irrigation on the various continents; more than 80% of which is situated in arid or semi-arid conditions.

About 85% of irrigated fields can be found in Asia, mainly in developing countries.

A further increase in irrigated lands is forecasted. Most world projections predict and recommend doubling the irrigated area until 2000. The environmental impacts of irrigation will most probably not only double, but in many cases multiply as a result.

Besides the beneficial effect of irrigation on yields, its detrimental effects are also well-known. According to international statistics and estimates, more than 50% of the land irrigated at present has been severely damaged by secondary salinization-alkalization as well as by waterlogging. This is partly due to the poor technology of irrigation and drainage, and partly to the improper selection of site, method and design of the irrigation systems. This phenomenon is known from very ancient times; the deterioration of the Mesopotamian plain which was transformed from fertile land to desert is only one of the many examples. Still, the process has not been arrested, and every year about 10 million hectares of irrigated land must be abandoned as a consequence of the process described above. This hazard is particularly great in developing countries. In Pakistan, for example, in the 1960s the impact of new irrigation systems on agricultural production was negative; in Iraq, the greater part of the irrigated land has been salinized, in South and Central America the new sugarcane plantations do not produce the expected yields because of salt accumulation. Secondary salinization, alkalization and waterlogging are the main hazard now, and in the uncertain future there are other hazards associated with the developing of irrigation systems.

While in the past neither the cause of secondary salinization was clear, nor the methods of its prediction and prevention were available, now we have the knowledge and ways of predicting and arresting this process; we even have methods for the reclamation of saline lands.

Unfortunately, during the planning and decision-making phase before the construction of irrigation systems, little or no attention was paid to the necessity of counducting a proper preliminary survey and seeking experienced opinion on the predictable consequences of the project. The same happens in the case of establishing large power stations and dams /Colorado, Assuan, etc./, just like when small or local irrigation systems are constructed. When salt accumulation appears, or waterlogging hinders the utilization of the land it is too late and too expensive to start those interventions which could have helped if made in due time and had been based on proper preliminary studies of the soil, subsoil and water interrelationships.

Acidification of soils - Particularly in the last decades of years a great amount of acid substances have been produced by industry, agriculture and communal activities. Emitted to the air either by carriers /by wind, precipitation/ or directly they contaminate the plant cover and soils. As a result vast areas of industrialized countries and their neighbours suffer from the acidification of soils as well as from the destruction of forests.

Soil acidification has developed particularly in soils developed on acidic or neutral parent materials particularly under humid conditions and consequently many fertile soils have become degraded and lost their productivity.

In Scandinavia, for instance, during thirty years a remarkable acidification of soils developed which affected not only the top layers of soils but also the deeper horizons. Parallel with this phenomenon, partly as a consequence of the increasing acidity, soluble toxic compounds also appeared in soil layers, i.e. aluminium, which reduced the fertility of the soils. Both "forest damage" and "soil damage" affect the negative consequences which include the adverse effect of acid pH directly, as well as its indirect effect through negative changes in nutrient status, physical properties, biological communities in the soil.

In several countries, i.e. in Europe, more than fifty percent of all cultivated soils has been exposed to the acidification processes and vast territories lost their productivity when the pH of soils was reduced with one, two or even more units during a few decades of years.

The combat against soil acidification includes not only the application of more advanced fertilizer techniques but also the control of sludge materials as well as introducing alternative technologies for industrial plants emitting mainly NO_x or SO_x gases.

Mechanical and agrotechnical destruction of soils - Agricultural practices subject the soil to the permanent mechanical effects of machines and animals. The processes involved and their results are many-sided and diverse, but generally it can be stated that the use of heavy machinery in modern agriculture has a number of consequential and increasing effects on the soil and ecosystem which are not always completely favourable. The repeated use of heavy machinery often destroys the structure of the soil.

In addition to the effects of such farm implements various other practices may also influence the mechanics, physics and chemistry of the soil. Besides a chemical buffering capacity, which can counterbalance changes in the contents of chemicals, toxic materials, etc., soils also have a mechanical or physical buffering capacity, i.e. a resilience which may counteract certain mechanical effects and restore the sustainable status of the system.

First, the consequence of grazing must be mentioned.

Grazing animals not only consume vegetation but also trample the soil, altering thereby its structure, compactness, etc. Overgrazing means not only depleting the plant and nutrient contents of the land, but also overstepping the limits of its physical and mechanical resilience.

The physical and mechanical changes caused by machinery, animals and other forces may result in chemical and biological changes in the ecosystem. The deterioration of soil structure may, for instance, entail a decrease in the water-holding capacity of the soil, a deficiency in the water available for plants and the degradation of the micro-environment of microorganisms, etc.

To combat the hazards of mechanical damages to soils and ecosystems it is necessary to:

- study the correlations between mechanization and its physical effects on the given agricultural and sylvicultural patterns, and
- elaborate, adapt and disseminate appropriate methods for preserving and improving the mechanical and physical properties of the soils.

Contamination of soils by harmful compounds - Apart from the above-characterized acidification process, the amounts of various chemical products contaminating the air, land and water have multiplied in the last decades and are leading steadily to a wide variety of environmental problems. The trend of increasing contamination of the ecosystems is expected to continue, in spite of international or local measures to arrest or at least slow it down. A number of various processes with different origins and specifications account for the contamination of soils and other renewable resources. The most important are:

- heavy metals /airborne or water-carried/,
- residues of pesticides,
- sludges, excrements from agriculture and animal husbandry,
- other organic and inorganic toxic materials and residues.

Contamination influences the ecosystem as a whole and the status and sustainability of renewable natural resources. The consequences of contamination are diverse and many-sided. Each of them, depending on local circumstances, will require specific analysis and modelling. There are many interrelations between the contamination of the ecosystem and other adverse effects.

Another example of complex environmental contamination is the effect of increasing motor traffic. The resulting air pollutants are carbon monoxide, nitrogen oxides and polycyclic aromatic hydrocarbons. In addition, heavy metals contained in gasoline /lead, copper, manganese/ are emitted with the exhaust gases and are primarily bound on submicron particles. The pollutants, during and after reaching the air, fall on land and water surfaces. Part of the pollutants absorb temporarily or permanently on soil colloids, but another part will influence the microorganisms of the soils and the plant and food chain. Most of these pollutants do not break down /heavy metals/, but accumulate and pose a permanent and increasing threat to the environment. Little knowledge has been acquired about the buffering capacity of soils and ecosystems in respect of pollutants.

The frequent contamination of soils, crops, etc. by toxic organic material from sludges, manure, etc. poses another problem significant also from hygienic and medical points of view.

It is difficult to estimate even roughly the hazards of soil contamination on a global scale, but its increase can be expected resulting in a continued decrease in fertile soils.

Anthropogenic radioactivity in soils - Table 14 gives an overview of natural radioactive elements in soil and bedrocks. This radiation, inherent to each ecosystem, although within a fairly wide range of fluctuation in concentration, finds modification in situ only over longer periods of slow geological evolution, except for the cosmic ray induced nuclides, which depend on the neutron density in the higher atmosphere of about 10 to 15 km altitude. Obviously, a fluctuation of the radiative input into the ecosystem influences the climate as well as the rate of natural ^{14}C formation.

Table 14. Natural radioactive elements in soil and vegetation /Annual report on environmental radioactivity, BMI /FRG/, 1983

Substrate	Radio-nuclide	Concentration Bq/kg /approx./
Soil	K-40	40 - 1000
	Po-210	10 - 40
	Ra-226	40
Top soil samples	Ra-226	40 /10 - 200/
	Po-210	2 GBq/km^2
Earth crust	K-40	700
	Rb-87	200
	Th-232	40
	U-238	40
Igneous rocks	K-40	300 - 1000
	Ra-226	20 - 200
	Th-232	40 - 600
	U-238	20 - 100
Sedimentary rocks	K-40	100
	Ra-226	20
	Th-232	10
	U-238	20

Inputs by human civilization and technology

They are unavoidable, oriented at legally enforced radiation protection ceilings. Their impact on changes of soils is exclusively by contamination, directly by deposition or indirectly via wind or water path. Main contributing components are:

- Agriculture: Major input is the natural ^{40}K with the potash fertilizer. Tracer research, applying radioactive or stable isotopes of the 15 plant nutrient elements /^{2,3}H, ^{14}C, ^{15}N, ^{18}O, ^{32,33}P, ^{34,35}S, ^{36}Cl, ^{22}Na, ^{28}Mg, ^{40,42}K, ^{45}Ca, ^{54}Mn, ^{55,59}Fe, ^{60}Co, ^{65}Zn, ^{67}Cu, ^{99}Mo/ render a nominal input only. Radiation measurements, applying safely enclosed radiation sources, such as for food or feed sterilization, for sterile male techniques in Entomology, for density and moisture measurements in soils with - and neutron-probes, do not affect the balance of anthropogenic radioactivity input in soils.

- Minig of Uranium and Thorium and also of coal involve release of radioisotopes into the biogeochemical environment. Facilities for reprocessing of nuclear materials are expected to release radioactivity into the environment and adjacent soils several orders of magnitude higher than the nuclear power plants. After abandoning the operation of nuclear power reactors, which have about 40 years life time, safe disposal of all the radioactive materials, especially the activation nuclides, such as ^{58}Co, ^{60}Co, ^{63}Ni, ^{51}Cr, ^{54}Mn, ^{59}Fe and others, imposes further problems. Estimates are, that again after 40 years ca 5% of the initial radioactivity still remain /HERRMANN, 1983/.

Radioactive fallout due to atomic bomb testing

From the whole set of fission isotopes of the original fallout only ^{137}Cs and ^{90}Sr are still measurable in soils of sufficient sorption capacity. The initially very important ^{131}J, with its t1/2 /half life period/ of 8.07 days only, is expired. ^{14}C and ^{3}H from thermonuclear testing are sustaining a "bomb ^{14}C and ^{3}H" activity. The bomb-^{14}C-level over time is shown in Fig. 12. ^{90}Sr with T1/2 of 28.1 y, measured on account of its radiation by a shielded low level proportional counter and ^{137}Cs with T1/2 of 30.23 y, are still existing in most soils. In 1967, almost at the peak of fallout contaminant, in Middle Europe the ^{137}Cs-level was about 800 to 3400 Bq.m^{-2}, the ^{90}Sr activity was ca 300 to 3700 Bq.m^{-2} /BECKER and SHARPENSEEL, 1989/. After the atmospheric bomb test stop by the USA and USSR the fallout activity was decreasing due to percolation, erosion, removal with the crops to almost nominal just measurable concentrations. The Chernobyl event gave rise to new ^{131}J, ^{134}Cs and ^{137}Cs contaminations in European soils.

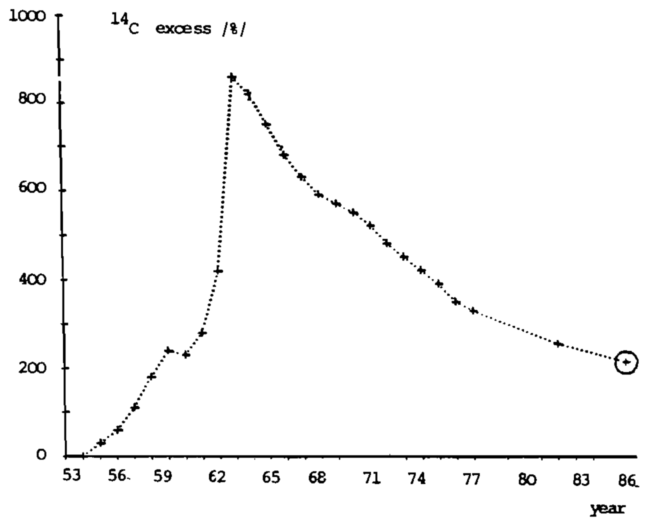

Figure 12. Bomb-^{14}C curve from the beginning of thermonuclear testing till present

Catastrophic events, such as from overheated nuclear power reactors

Notwithstanding a certain ambiquity regarding minor leaks and radiation spills, a number of historic records of reactor accidents, which led to considerable contaminations of soils /BECKER and SCHARPENSEEL, 1989; ROTH and WELLER, 1987/ exist:

- The Sellafield/Windscale accident, Oct. 9, 1957 released ca 7.4.10^{14}Bq ^{131}J, 4.4.10^{14}Bq ^{132}Te, 2.2.10^{13} Bq ^{137}Cs, 3.10^{12} Bq ^{89}Sr and 7.4.10^{10}Bq ^{90}Sr over Britain and West Europe.

- At the end of 1957 an explosion of a plant for nuclear waste treatment near Sverdlovsk, contamination of ca 1600 km^2 with mostly ^{90}Sr /6.7.10^7 to 1.3.10^8 Bq ^{90}Sr/m^2 of soil/ and some ^{137}Cs.

- June 18, 1978: release of ca 9.3.10^{12}Bq from the leak in nuclear power reactor Brunsbüttel.

- March 28, 1977: lost a nuclear power plant. Three Miles Island II in Harrisburg: 113 m^3 active water and ^{131}J plus noble gases from a gas pressure built-up in the containment /ROTH and WELLER, 1987/.

- April 26, 1986: in Chernobyl a nuclear explosion, graphite fire and core melting led to a large scale contamination of the atmosphere and also of the soil, especially of European countries, and to an emission of radionuclides, amounting to ca. $3.8.10^{18}$ from a content of 10^{19} Bq /KNÖCHEL et al., 1988/. As in other observed reactor accidents the thermic conditions favor release of the alkali nuclides to the earth alkali ones, which are so strong in bomb fallout of the whole set of fission nuclides. Such major accidents can lead to deposition of radioactive contaminants all over the world /OECD, 1987/. Measurements in whole profile depth indicate a sustained depth transfer of the ^{137}Cs and ^{134}Cs /Table 15/.

Table 15. Inventory of the reactor core and released parts of the radionuclides during the accident of Chernobyl. Activities are related to May 6th, 1986.

Nuclide	Halflife /d/	Inventory /Bq/	Released part /%/
^{85}Kr	$3.93.10^{3}$	$3.3.10^{16}$	up to 100
^{133}Xe	5.27	$1.7.10^{18}$	up to 100
^{131}J	8.05	$1.3.10^{18}$	20
^{132}Te	3.25	$3.2.10^{17}$	15
^{134}Cs	750	$1.9.10^{17}$	10
^{137}Cs	$1.1.10^{4}$	$2.9.10^{17}$	13
^{89}Mo	2.8	$4.8.10^{18}$	2.3
^{95}Zr	65.5	$4.4.10^{18}$	3.2
^{103}Ru	39.5	$4.1.10^{18}$	2.9
^{106}Ru	368	$2.0.10^{18}$	2.9
^{140}Ba	12.8	$2.9.10^{18}$	5.6
^{141}Ce	32.5	$4.4.10^{18}$	2.3
^{144}Ce	284	$3.2.10^{18}$	2.8
^{89}Sr	53	$2.0.10^{18}$	4
^{90}Sr	$1.02.10^{4}$	$2.0.10^{17}$	4
^{239}Np	2.35	$1.4.10^{17}$	3
^{238}Pu	$3.15.10^{4}$	$1.0.10^{15}$	3
^{239}Pu	$8.9.10^{6}$	$8.5.10^{14}$	3
^{240}Pu	$2.4.10^{6}$	$1.2.10^{15}$	3
^{241}Pu	$4.8.10^{3}$	$1.7.10^{17}$	3
^{242}Cm	164	$2.6.10^{16}$	3

Int. At. En. Agency, Chernobyl accident, Safety Series no. 75 - INSAG - 1. Vienna, 1986

The transfer within the trophical planes and the foodweb, modifiers

Since radionuclides in the soil are of potential danger mainly due to their import into the nutritional web, especially the transfer factor from soil to plant has been of central interest. However, a universally valid transfer factor cannot exist, neither for all soils nor for all plants. There are modifiers to be observed; in the soils especially the clay and organic matter content, pH, Eh, CEC, regarding plants like cereals, tuber plants, leafy vegetables, fruits and fruit-like vegetables.

Environmental radiation, changing climate, changes in soils

The Milankovich 40,000 years's cycle for cold periods as evidence by intense evaporation from an enclosed polar water body with the consequence of snowfall and rising albedo, leads to less absorbed radiation and warming of the land surface. Similarly, dust clouds from volcanism or bomb testing can exert special cooling effects. Inversely, degassing of subduction zones or volcanism can promote a GHE /greenhouse effect/.

Radioactive inputs by bomb tests or reactor accidents into soils are more consequential than inputs into a fast moving atmosphere or a fluvial medium-like water. Soil adsorbs and stores the radio-nuclides for longer periods; it is kind of resentful against radionuclide insults by maintaining the state of contamination and the readiness to transfer radioactivity in the nutritional cycle.

With the need to curtail consumption of fossil fuel with its GHE promoting CO_2 and CH_4-release, nuclear power plants will be sustained till nuclear fusion reactors or the hydrogen photovoltaic technologies become economically feasible. Thus, soil exposure to continued radioactivity inputs must be envisaged and kept manageable.

In spite of the numerous processes resulting soil degradation we must oppose to such opinions often appearing not only in various medias but sometimes even in technical literature, which nearly classify human-activities as a catastroph for nature. Human activities, which have both positive and negative environmental consequences, should be studied and evaluated in space and time concretely, because many good examples are available about the beneficial effect of production on the sustainability of the environment. Numerous international projects investigate not only the adverse effect of production on soils but also the methods and systems for soil conservation, increasing the productivity and sustainability of the biosphere.

Chapter VII

FUTURE CHANGES OF THE PEDOSPHERE

There is no comprehensive body of pedological theory that adequately integrates environment, energetics, dynamics, distribution and abundance of soils throughout the world. The present environments in which soils occur provide glimpses of how, when and why soils respond as they do. Generalizations contain unspecified levels of uncertainty that hinder our understanding of the effects of climate change. The natural and anthropogenic processes previously discussed provide a basis for extrapolation.

Many global climate change models are being developed, usually with common global trends but lacking regional specificity necessary for soil science to offer concrete suggestions for particular areas or regions. Some concepts of changes in soil nutrients, soil moisture regimes, and physical stability of landscapes that may be associated with possible climatic events guide our efforts to fill the gaps of our knowledge.

Some degree of warming of the globe due to the increase of "greenhouse" gases currently in the atmosphere appears likely. Most global climate models indicate warmer temperatures especially in the northern polar region.

If the temperatures rise in the tundra areas of the northern hemisphere, then vast amounts of permafrost would presumably meet.

- Organic matter decomposition in the soils would increase releasing significant amounts of CO_2 to the atmosphere. Nitrogen and organic carbon, and other nutrients would also be more available for biocycling by the biota.

- Rising groundwaters are apt to occur closely to the soil surface and in many places waterlogged soils and marshy areas would result. The reduction of iron compounds associated with the gleyzation process would increase, changing the morphology of many previously well-drained soils.

- The unfrozen soil likely would release methane and other gases trapped in the permafrost itself.

- The soil processes associated with more southerly zones possibly would be dominant in the thawing permafrost areas and would serve as references for predicting additional changes in the soils.

If the temperature rises in the northern boreal forest /taiga/, then the processes affecting soil development likely will be accelerated.

- Litter and humus decomposition feasibly would be accelerated as would mineral weathering. This increased pool of plant nutrients and warmer growing season temperatures might possibly favor other tree species and some extreme instances may be unfavorable for sustaining the northern boreal forest. Humus incorporation into the soils and increased cycling of biological compounds likely would shift the set of soil processes such that the soils would begin to develop morphologies and features associated with soils near the southern boundary of the present forest cover.

If the temperature and regional precipitation patterns are modified in the forest-grassland transition zones, then the resulting soil moisture and temperature regimes may be favorable for crops whose present ranges are farther south.

- The shift of cropping patterns to utilize adapted or newly bioengineered plants could markedly affect the rate and intensity of anthropogenic changes in soils. The changing cultivation and soil management practices probably would be similar to those now utilized in areas farther south. Soil fertility and humus maintenance possibly would become of major importance as corn and soybeans are grown in previous small grain and pasture areas.

If the climate patterns change then the existing subhumid and semiarid portions of the vast plains of the northern hemisphere may undergo more extremes of weather mainly as drought and hotter summers.

- These changes would result in additional ecosystem stresses that make the soils more sensitive to degradation. Similar conditions and corresponding soil processes exist in the present day semiarid-arid transition areas where water management and salinity control are of concern.

The changing climate of the globe is not expected to significantly alter the existing climates in the tropics, thus the soil processes currently acting in those ecosystems presumably would remain about the same.

- Conversion of tropical forests to other types of land cover are likely to have more dramatic effects on soils and local weather than global shifts of climate. The loss of the forest recycling of moisture and the exposure of soils having delicate nutrient balances increases the need to understand and manage the ecosystems carefully for sustainability.

If the climate warms, then there may be a rise of sea level that would inundate many coastal areas.

- The flooding of many areas would likely result in the loss of many existing wetlands. These wetlands serve as large sinks of carbon and other geochemicals as well as providing unique habitats for many kinds of aquatic and terrestrial wildlife and plant species. On one hand, the submergence of these soil environments removes their soils from the land base available for food, fiber and shelter.

- A rise in sea level would increase the natural base level that triggers large scale erosion. At the coastal fringes previously buffered coastal lands may be subjected to increased erosion and degradation as the salt water intrudes farther inland. Soil processes may shift toward those that currently exist in the adjoining areas.

If world population increases occur as suggested by several world organizations, then the demand for food and fuel will sharply increase in many developing countries.

- The environmental stresses resulting from more people using the available resources probably will lead to additional degradation of the ecosystems. Soil erosion, changes in salinity and alkalinity, reduced productivity, and problems of water management may occur. The anthropogenic soil changes of processes and of soils have previously been discussed and would be relevant to understanding and mitigating future soil changes in these situations.

- The expansion of cities, industries and their related infrastructures also utilize soil resources. Some are removed from further consideration while others may require reclamation or drastic modification to perform in acceptable ways. The range of possibilities of use and their consequences are not fully integrated into a coherent perspective of global soil change.

It is obvious that the fragmented knowledge of soil resources is not sufficient at this time to stand on its own. The complex interactions of man with the environment are not well enough understood to prepare prescriptions for all situations. The urgency to pool our knowledge with other scientific and social information is evident through the continuing abuse of ecosystems.

The future changes of soil depends very much on the policies established and implemented by the governments of all nations. Soil science is ready to provide the best available information about the behavior and limitations of soil resources and to encourage the wise stewardship of this one world.

Chapter VIII

SPATIAL SOIL DATABASES AND MODELING

Rationale and objectives

Each of the other chapters of this treatise discusses one or more aspects of the role of soils in global change. These chapters describe in detail the variability of the components and processes of soils and the influences which human activities have had on them. A discussion of soil classification systems describes the need for universal, standardized procedures for classifying, describing and mapping global soils resources. After more than a century of the development and use of a common concept for inventorying soils resources, the challenge of entering the massive quantities of soils data into a standard, uniform, usable database remains.

One of the keys to understanding and quantifying the role of soils in global change is to have a global soils and terrain digital database which is accurate, accessible and available for analysis in combination with other resource databases, such as climate, geology, topography, land use, land cover, and others. The opportunities offered by this combination will open new horizons for our understanding of soils resources, terrestrial ecosystems and their roles in global change and environmental degradation.

This chapter will address the issues related to the application of recently developed and continually developing information technology to provide resource managers and policy-makers with accurate, timely, useful information about soils and related Earth resources. Soils information may be considered in two categories:

a/ the inventorying of soil resources, and
b/ the monitoring of changes in these resources.

In particular, we will address the design and use of spatial /cartographic/ databases and the kinds of attribute data for describing and/or quantifying all soil and terrain mapping units.

The needs for such databases become more important as the human demands for and pressures on soils and related resources increase. More and better information about our soil resources is important for the improvement of food productivity in sustainable systems, the implementation of more effective control and management of land degradation processes, the maintenance and restoration of environmental quality, and the assessment of the role of soils in global change.

The objectives of this chapter are:

a/ to present basic concepts for the design of spatial databases for soils and related resources,

b/ to suggest some important uses of soils databases, when used alone and in combination with other natural resources and socioeconomic data sets.

Introduction to soils databases

The use of computers for the storage, retrieval, manipulation and analysis of large quantities of data has become the norm in many areas of technology. Soil science is no exception. There is a keen interest among soil scientists around the world to enter soil maps and descriptions into digital databases so that these data sets can be registered to and combined with other data sets /geology, climate, hydrology, land use, topography/ for modeling such processes as land degradation, soil productivity, and rates of change. However, much research and development is yet to be done before this technology can be used operationally as a tool for natural resource management at different spatial and temporal scales.

Since this chapter deals with a complex of emerging technologies, perhaps it will be useful to define a few 'database' terms which have come into general use in recent years.

a. Database system. A computerized record keeping system whose overall purpose is to maintain information and to make that information available on demand /DATE, 1989/.

b. Geographic information system /GIS/. A computer-based that provides the following sets of capabilities to handle georeferenced data: input; data storage and retrieval; data manipulation and analysis; and output /ARONOFF, 1989/.

c. Attribute data. Descriptive /non-graphic/ data related to a point, line or area element in a GIS /BURROUGH, 1986/.

d. Relational database. A collection of relations that contains all the information that is to be stored in the database /JACKSON, 1988/; a 'way of looking' at the data in the database /DATE, 1986/.

e. Database management system /DBMS/. A collection of programs that enables users to create and maintain a database. Typically, a DBMS is a general-purpose software that facilitates the processes of defining, constructing and manipulating databases for various applications /ELMASRI and NAVATHE, 1989/.

f. Spatial database. See geographic information system.

The main components and functions of a geographic information system are presented in Figure 13. The data Input component permits the conversion of data from its original format into one that can be used by the GIS. An ideal GIS may utilize data from different sources, such as remotely sensed, cartographic, tabular and digital data. The Storage and Retrieval component of the GIS includes those functions needed to store and retrieve data from the database. These functions affect the efficiency of the system in performing all operations with the data. The data Manipulation and Analysis component makes it possible to generate new information from existing data in the GIS. The Output and Reporting component of a GIS refers to the different ways the data are displayed and the results reported to the user/s/ of the GIS, i. e. maps, tables, figures, others.

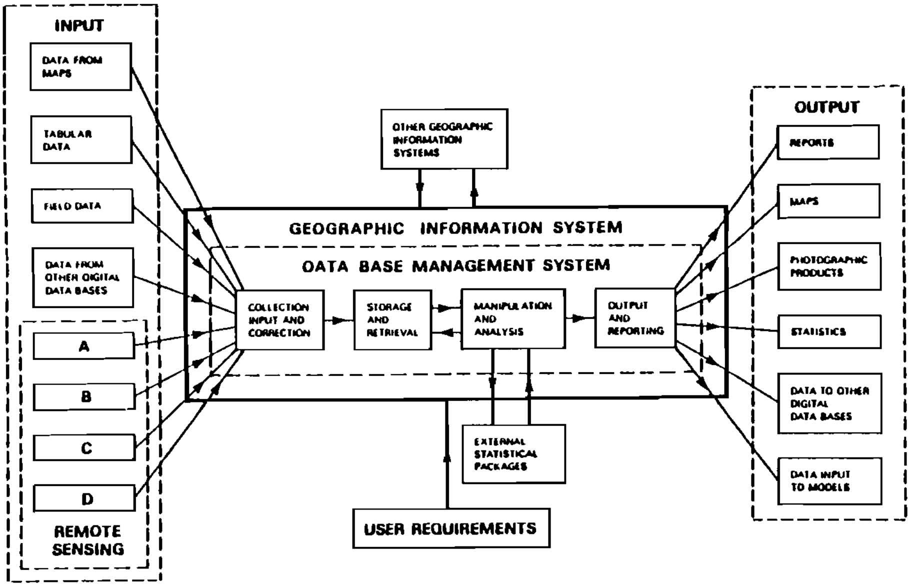

Figure 13. Conceptual schema of the main components and functions of an idealized geographic information system /CRACKNELL, 1986/

Central concepts

We have reached a point in the evolution of science and technology that we can now conceptualize and study the Earth as a system. No previous human generation has had the tools which made it possible to consider the Earth as a system - to observe, measure, analyze, and model the various components of the system. We are fast approaching the capability through rapidly emerging technologies to improve our understanding of the Earth system. A brief review will be given of a combination of evolving technologies which are beginning to provide these tools to study the Earth system.

Data collection and preprocessing

Soil scientists have used photographic methods for half a century to observe and record variations in soils. But it has been only in recent years that a broad array of data acquisition, storage and analysis techniques has provided a new approach to the study of soils. The capability to observe the Earth's surface repetitively from space has added a new dimension to the study of soils and land resources. Many current laboratory, field, air- and spaceborne sensors now provide quantitative spectral, spatial and temporal data about Earth surface features. A new integrated package of sensors planned and designed by an international science and engineering effort is scheduled for launch into polar orbit after the mid-1990s /NASA, 1988/. Leadership for this effort is being provided by the US National Aeronautics and Space Administration under its Earth Observing System Program /EOS/. In this Program an integrated package of sensors will obtain high spectral resolution /100 to 200 reflectance bands of 10 nm bandwidth/, multispectral emittance, microwave and radar data simultaneously of the surface of the Earth. This instrument package promises to provide a valuable new tool for studying and characterizing soils and related resources, but at the same time it creates the challenge of handling an enormous amount of data.

One of the ways for overcoming these problems is the use of geographic information system technology /ESTES, 1985/. An integration of remote sensing and GIS technology is an evolutionary extension of the capabilities of current GIS technologies /EHLERS et al., 1989; SIMONETT, 1988/. Another important area of technological advance which will have a significant influence on the quality of global geographic information systems is that of geo-positioning. On a global basis cartographic accuracy of soils and terrain maps in terms of geodetic positioning of the Earth surface is of rather poor quality. In many countries, the lack of geodetic referencing is a major handicap for progress in soil science /BIE, 1984/. If we are unable to find a point of reference, we cannot relate soils data to other resources data and to the world context. Positional accuracies of spatial features in a GIS are of critical importance to many users, and they cannot exceed those of the original data source /MARBLE and PEUQUET, 1983/. A geodetic reference framework, which is the spatial foundation of any GIS, provides an accurate and efficient means of positioning data /NATIONAL RESEARCH COUNCIL, 1983/, and allows compability for the resulting spatial information products /EPSTEIN and DUCHESNEAU, 1984/.

Fortunately, advances in satellite positioning technology may give us the opportunity in the future to pinpoint a soil observation anywhere in the world to within 5 meters /BIE, 1984/. It is essential that we have the capability to overlay accurately in a spatial database soils and terrain data onto other natural resouce data /climate, geology, hydrology, topography, land use, land cover, other/ if we are to use most effectively our soils information in predicting and/or modeling land use capability, soil productivity, land degradation and rates and kinds of change.

Data analysis

The computer revolution during the past three decades has changed dramatically the way soil scientists and other Earth scientists analyze and interpret data. Image processing, data sorting, database management systems, statistical analysis and mathematical modeling techniques are implemented on increasingly powerful microcomputers and generally available to and useable by individual scientists. Without these capabilities it would not be feasible to present the concepts and the recommendations which are discussed in the latter part of this chapter.

Although the major emphasis in this chapter may be on the design and structure of spatial and attribute databases, it is important to stress that the power and utility of any database reside in data analysis. That is, the data analysis methods must be capable of addressing the complex data sets, analyzing the data and extracting useful information, and performing these tasks efficiently and accurately.

The rapid development and expansion of data acquisition and analysis technologies has greatly enhanced the growth of geographic information system /GIS/ technology. Whereas conventional methods of handling and analyzing spatial and attribute data greatly limit our ability to synthesize and integrate data even about soils, GIS technology provides a methodology which allows us to combine, synthesize and integrate many kinds of resource data - - multi-source, multi-stage, multi-spectral, multi-temporal, multi-resource and multi-user. Even now we can transform automatically one map projection to another. With further development and improvement of GIS technology, we should be able to move more readily from one scale to another.

Soils and terrain database design

It is possible with today's technology to generate large amounts of data about natural resources in a variety of ways. Advances in remote sensing and related technologies within the next decade will increase the data acquisition capabilities of an array of polar-orbiting satellite sensors from the current 10 megabits per second to 800 to 1000 megabits per second. Of course, soil scientists may be interested in only a small fraction of these data, but very important soils and terrain data will be imbedded in this massive data set.

Spatial databases for soils /or any of the natural resources/ on a global basis contain an extremely large volume of data with geographic /coordinates/ and descriptive /attribute/ information. Such systems require the capability to handle large amounts of data and to relate the spatial and non-spatial data components in the database. The larger the amount of data to be processed, the greater the amount of processing time required. The amount of data in the database is directly related to the efficiency of searching for specific data. As the size of the database increases, the time for search within the database increases.

One of the critical problems which must be addressed in the development of any worldwide database is the diversity of classification systems which are used to describe a particular component of the Earth system. Not only are there significant differences between classification systems, but individual classification systems may change. As Earth observating technology advances, our knowledge about the Earth and its components and processes changes, and, consequently, the need to change or adapt classification systems may become advantageous. It is essential that any global database should be designed to respond and be able to accommodate such changes.

The database designer/s/ must take into account not only the diversity of data sources, but also the different scales and map projections with which soils data are represented.

Although the FAO/UNESCO Soil Map of the World was not generated initially for entry into a digital database, the problems related to a diversity of sources, scales, map projections and data quality were enormous for the generation of this world map at a scale of 1:5M. These same factors of diversity provide serious challenges to the current World Soils and Terrain Digital Database /SOTER/ Project initiated by the International

Society of Soil Science /ISSS/ in 1986 for the purpose of generating a new world soils and terrain database containing map and attribute data at a nominal scale of 1:1M. Funded by the United Nations Environment Programme /UNEP/, Phase 1 of this Project includes an area of 250,000 sq km in portions of Argentina, Brazil and Uruguay /BAUMGARDNER and VAN DE WEG, 1989/. The most difficult task in this Project has been to correlate and translate cartographic and descriptive data from three different soil classification and mapping systems into a uniform, standardized method of entering data into the SOTER Database. Correlations across country boundaries are necessary. It is essential to find a common set of descriptive parameters and to avoid inconsistencies and ambiguities in definitions. Soil and terrain mapping units across political boundaries have to 'close'. Another major problem to consider when creating a global soils database is edge-matching between adjacent soil maps as they are digitized and entered into the database. This edge-matching capability is essential for transforming the data from a sheet-based to a 'seamless' spatial database /MARBLE, 1988/.

A global soils database, such as the SOTER database, will use existing thematic data. It will not develop new methodologies to acquire data. Because of that, an important point to consider when creating a global soils database is the diversity of data sources. Soils data are available around the world at different scales, different projections and described according to different classification methods. Of course, there are as yet large land areas of the world for which no well-developed soils maps exist. In such areas it is anticipated that remote sensing techniques will be combined with traditional soil survey methods to provide cartographic and attribute data for the soils or these unmapped areas.

In considering the design of a global soils database, it is important to realize that the same kinds of problems and challenges confront those who are developing databases for other components of the Earth system. Therefore, a global soils database should be designed to be one component of a more comprehensive global geographic information system which will include data sets of other resources.

The complexity of the design of an integrated database for natural resources necessitates a structured approach to database design. Database design is the development of the structure of the database, the definition of its contents, and the validity of the data which are to be placed in it /MARBLE, 1988/. Since database design is normally done prior to the implementation of the database, it is then necessary to communicate with potential users of the database in order to understand their needs so that these needs may be incorporated into the design process. A good design means an efficient database.

Design methodologies were first developed for non-spatial data. These methodologies have been and are being adapted for use in spatial databases where it is essential to 'anchor' spatial data and their relationships. Spatial, or geographic, data have four major components: geographic positioning, attributes, spatial relationships and time /ARONOFF, 1989/. Geographic positioning refers to the location of a feature on the surface of the Earth. These locations are recorded by a coordinate system /i.e. latitude/longitude; Universal Transverse Mercator, other/. The accuracy of this positioning will depend on the scale at which data are recorded.

Attributes, or non-spatial data, almost always accompany spatial data. They describe the spatial data. For design purposes it is important to know not only the amount of data to be incorporated into a database, but also the ratio between spatial and attribute data. Knowledge of this ratio is important to assess the spatial data handling requirements, particularly for data encoding /CALKINS, 1984/.

Geographic features are spatially related in a complex way; these spatial relationships can be expressed by using topology - a mathematical procedure for explicitly defining these spatial relationships. Time is a very important component of data. Knowing when data have been collected can be critical to users /ARONOFF, 1989/.

Data quality

Quality of data is important for the rational assessment of a situation or condition. What is data quality? Although it is difficult to provide one satisfactory answer to this question and, at the same time, to satisfy the many users of different kinds of natural resource data, there are some common rules for evaluating data quality that can be used for different applications /soils, vegetation, land use, other/.

The concept of data quality suggests usability and versatility of data /MEAD, 1982/. The characteristics that affect the usefulness of data can be divided into three categories /ARONOFF, 1989/. The first category includes factors that pertain to the individual data, such as positional accuracy, attribute accuracy, consistency and resolution. In general, these factors are scale dependent. A second category includes data quality factors that pertain to the data set as a whole: completeness of data, time of data acquisition, how the data were produced /lineage/. The third category includes factors that are specific to the organization that will be using the data, such as accessibility and cost /ARONOFF, 1989/. A list of factors that affect data quality based on the experiences of users of natural resources data was prepared by MEAD /1982/. Besides those discussed above, he includes data format and degree of modification necessary to meet the users' needs.

Quality of data is related to cost. The higher the quality of data the greater the cost. It is costly to collect data and to store it. The

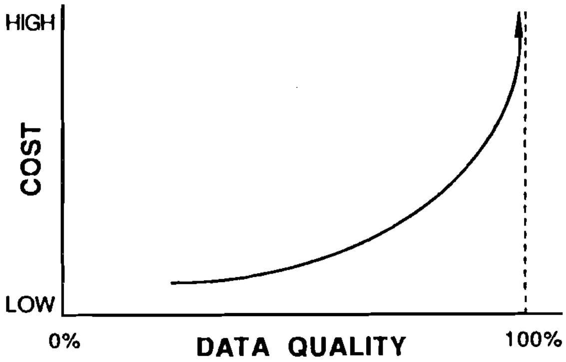

Figure 14. Relationship between data quality and cost /adapted from ARONOFF, 1989/

trade-off between cost of data and quality of data is illustrated in Figure 14. The quality of data to be included in a database, and therefore in a GIS, should depend on the future applications of the database/GIS. The optimal data quality is the minimum level of quality that will meet the objectives of the user.

Data errors

Because of the many different factors that can affect quality of data, there will always be errors associated with the generation of data. Geographic data are represented by maps, and errors are normally associated with data collection and data processing. Data collection errors, or source errors, relate to positional accuracy of the data and the description of the data /ARONOFF, 1989/. The accuracy of digital terrain and soils information is a function of the size of the sampling interval in relation to the variability of the surface /BURROUGH, 1986/. Subsequent manipulation of the data, or operational errors, contributes to the total error /ARONOFF, 1989; CHRISMAN, 1987; WALSH et al., 1987/. This problem is aggravated when working in the digital environment where manipulation of data is very easily done through analysis and modeling. Depending upon the level of error in the source data and through its manipulation, GIS products may possess significant amounts of error yielding results of questionable accuracy /WALSH et al., 1987; VITEK et al., 1984/. There can also be a serious misuse of the data when maps that were compiled for one purpose are used for other purposes for which they are not suitable /BEARD, 1989/.

Designing a global soils database

Since large amounts of data are to be included in a global soils and terrain database, it is very important to have a database designed for efficiency and avoidance of obsolescence. In the process of designing a database it is essential to identify those objects about which information must be recorded in the database. These objects may be either concrete or abstract /DATE, 1986/.

A database design process involves several steps /Figure 15/, the first of which is the defining of data requirements and analysis. During this step the objectives of the database and its specific requirements should be formulated. All the spatial and attribute data to be included in the database should be identified. Availability and format of data should be ascertained; hardware configuration requirements must be considered; and a survey of potential users and their sophistication should be completed.

The second step is the conceptual design. In this step all users' requirements are to be represented and integrated. The entities of interest to the project should be identified, and the information about those entities should be recorded /DATE, 1989/.

The next step is the mapping of the conceptual design into a data model. This step involves the transformation of the conceptual design into a data model of the database management system, i.e., relational, hierarchical, network. The final step is the physical design of the database, when the internal storage structures are defined and the data are organized /ELMASRI and NAVATHE, 1989/ The database is implemented using a commercial database management system. The mapping step may be seen as the 'link' between the conceptual and the physical design of the database.

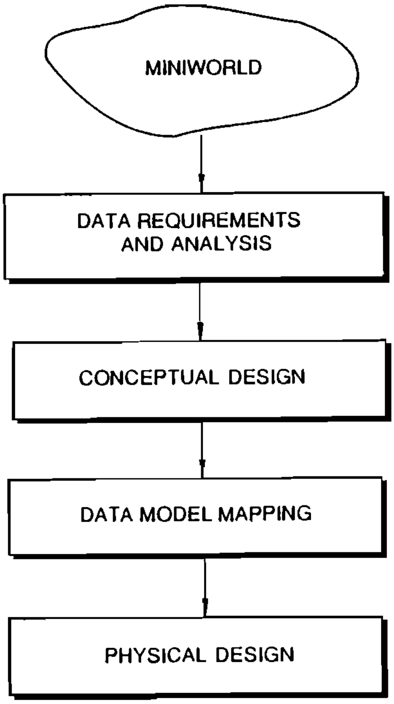

Figure 15. Flow chart for database design /adapted from ELMASRI and NAVATHE, 1989/

Conceptual design of a global soils database

A conceptual design provides a visualization of the existing relationships among the different variables to be included in the database according to the users' views, regardless of the database management system in which the database will be implemented. For this purpose, the Entity-Relationship /ER/ approach is strongly recommended as a general methodology to database design because it is closer to the users' perception of the data and is independent of the system that will be used physically for storing the data /ELMASRI and NAVATHE, 1989; MARBLE, 1988; CALKINS and MARBLE, 1987/. The ER model can integrate individual user views of the database into a global view, or integrated conceptual model, which will be the base for subsequent implementation of the database /CHEN, 1977; CALKINS and MARBLE, 1987/.

The ER model is a high-level conceptual model originally proposed by CHEN /1977/. This model describes the elements of a database /Entities/, the relationships between the elements /Relationships/, and the attributes associated with either the elements or the relationships. An entity is an object or thing in the real world with an independent existence. A relationship is the set of associations and/or linkages between entities. Attributes are the characteristics that describe entities or relationships. Entities, relationships and attributes can be represented through ER Diagrams, in which an entity is represented by a rectangle, a relationship is represented by a diamond shape, and attributes are represented by ellipses /Figure 16/.

CALKINS and MARBLE /1987/ utilized the ER approach to design a master cartographic database containing transportation features for the Rand McNally Road Atlas. FERNANDEZ et al. /1990/ used the Enhanced ER /EER/

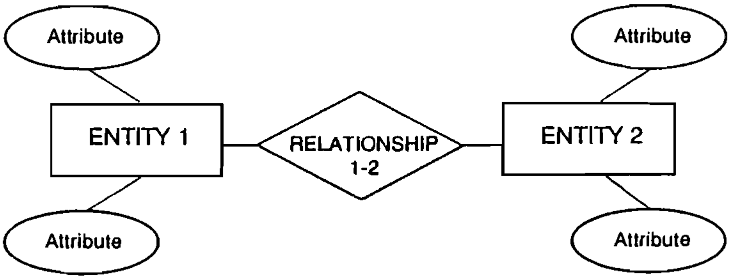

Figure 16. Graphic representation of the Entity-Relationship Model

model to design a a spatial soils database at a detailed /large spatial scale/ level. The EER approach incorporates additional modeling concepts into the ER model to account for more complex database requirements /ELMASRI and NAVATHE, 1989/. The soils data included in this database were obtained from existing surveys at a scale of 1:24,000. Although this is a detailed spatial database, this example illustrates conceptually the application of the ER approach to the design of a spatial soils database /Figure 17/. For simplicity only the entities and relationships are included in this figure. Several attributes have been identified and incorporated into the original design according to the objectives and applications of this database. This design is now being mapped into the relational model for implementation on a microcomputer /FERNANDEZ et al., 1990/. Through the design process it is important that provision be made to eliminate redundancy and inconsistency of data as they appear.

A global soils database, such as the SOTER Database, will use existing thematic data. It will not develop new methodologies to acquire data. Because of that, an important point to consider when creating a global soils database is the diversity of data sources. Soils data are available around the world at different scales, different projections and described according to different classification methods. Of course, there are as yet large land areas of the world for which no well developed soils maps exist. In such areas it is anticipated that remote sensing techniques will be combined with traditional soil survey methods to provide cartographic and attribute data for the soils of these unmapped areas.

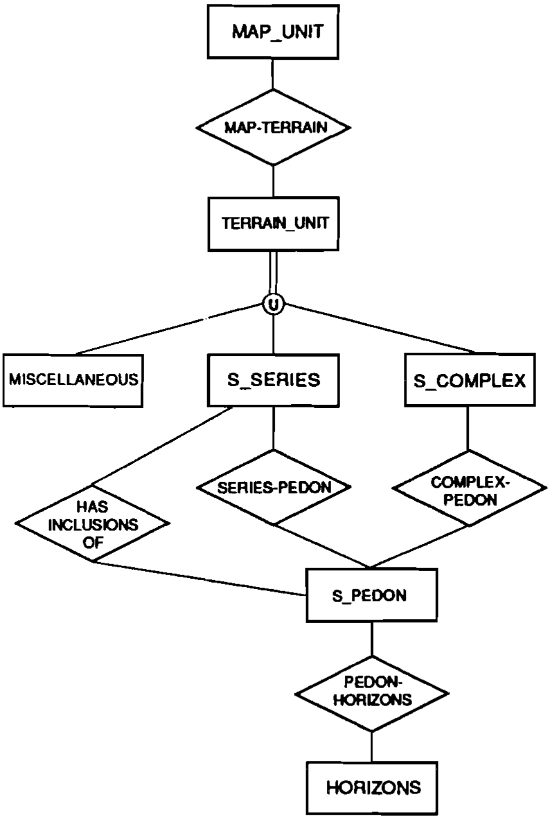

Figure 17. The Enhanced Entity-Relationship schema for a detailed spatial soils database /adapted from FERNANDEZ et al., 1990/

Use of soils and terrain database in modeling global change

The use of a soils and terrain database will be considered under two conditions. The first will be the use of the database without other resource databases. The second will be the use of the soils database in combination with one or more other resource databases.

Several possible applications of a soils and terrain database which includes map /polygon/ and attribute /descriptive/ data are suggested. In general, the applications will apply at different spatial resolution for use at different levels of detail - local, provincial, national, global.

Assuming that the database contains data in adequate detail at the appropriate scale, the database may be queried to provide thematic maps and/or tabular and descriptive data relating geographic distribution for the following soil characteristic and conditions:

a. levels of organic matter content
b. severity of rainfall erosion

c. severity of wind erosion;
d. variation in moisture holding capacity;
e. internal drainage status;
f. classes of degree and length of slope;
g. geographic distribution of various other physical and chemical; properties of soils.

Additional data sets in combination with a soils and terrain database will add significantly to the possibilities for the extraction of useful information from the soils data. This combination is essential for modeling the terrestrial ecosystem and its interactions with other components of the Earth System. The combination of soils, topographic, stream network, land use, land cover, and climatic data will provide data essential for modeling various conditions and processes related to global change and environmental degradation. Some of the more critical modeling possibilities are:

a. assessment of the human impact on rates of change in the terrestrial ecosystem;
b. quantitative assessment of the impact of agricultural chemicals on contamination of soils, surface water, and groundwater;
c. identification, location and geographic distribution of point and non-point source pollution of water resources;
d. soil loss prediction;
e. potential agricultural productivity;
f. assessment of land use suitability.

Many other problems in the modeling of changes in the terrestrial ecosystem can be addressed once the spatial and attribute databases are in place.

If these data sets can be combined with seasonal and annual updates of data derived from Earth observing systems, yet another dimension can be added to the capabilities. The temporal dimension will provide the capability to measure rates of change and to develop more precise prediction models.

Still another dimension to the utility of the spatial and attribute databases can be achieved with the addition of socioeconomic data to the information system. Some of the kinds of issues which might be addressed and modeled with this expanded database include:

a. quantitative assessment of population density on land degradation;
b. impact of government policy on agricultural productivity;
c. influence of government policy on agricultural production and resource allocation;
d. impacts of different socioeconomic and cultural constraints on agricultural productivity;
e. assessment of the effects of government policy on global change.

From the rapid development and expansion during the past two decades of the information sciences, including the areas of data acquisition, analysis, storage and dissemination, it is not unreasonable to predict that by the end of this century, both the data and the processing capabilities will be available to perform the kinds of analysis and modeling which have been described above. It is important that the community of soil scientists be prepared to participate in the development and utilization of these capabilities.

Chapter IX

CONCLUSIONS AND RECOMMENDATIONS

Soil changes are bound to occur as a result of many natural and anthropogenic changes in the environment and its elements, atmospheric temperature, precipitation, evapotranspiration, composition and depth of groundwater. These changes will have an impact on four major soil components:

- soil forming processes /e.g. eluvial and illuvial processes will evolve with shifts of climatic belts/
- soil physics /e.g. through erosion, drainage, water balance/
- soil chemistry /e.g. nutrient contents, salinity, acidity, nitrification and denitrification/
- soil biology /e.g. organic matter content, biological activity, methane formation/.

The time dimension over which these changes will occur differs widely:

- changes which will occur in the short term /immediately or within a few years/ concern the soil temperature regime, the soil moisture regime, migration of easily soluble substances, biological activity;
- changes which will occur within a few decades concern acidity, salinity, alkalinity, permafrost boundary, gley phenomena, litter composition and the stability of soil structure;
- changes which will occur within hundreds of years concern humus content, C/N ratio, secondary carbonate accumulations, cation exchange capacity, migration of Fe, Al and clay;
- changes which may occur over thousands of years concern changed pathways of soil development leading to a switch from one genetic soil group to another.

In order to assess the magnitude, timing and impact of soil changes at a global scale additional research will be needed to obtain the necessary basic data, to ensure comparability of information from different parts of the world and to monitor changes in function of a common reference base:

1. Update the inventory of the world's soil resources /e.g. on the basis of the FAO/UNESCO Soil Map of the World and SOTER/.

2. Establish and adopt an international system of soil classification /e.g. on the basis of the International Reference Base for Soil Classification or the revised legend of the FAO/UNESCO Soil Map of the World/.

3. Study the CO_2 cycle of soils and establish its contribution to the CO_2 content of the atmosphere.
4. Quantify and geographically delimit various forms of soil change /erosion, salinization, loss of organic matter, loss of plant nutrients, toxicities, waterlogging, e.g. on the basis of the GLASOD project of UNEP/ISRIC/.
5. Identify and quantify the impact of changes which are detrimental for the soil's production potential, including effects of improper human interventions.
6. Identify and quantify changes which enhance the production potential of the soil, including effects of beneficial human interventions.
7. Study the behaviour of polluting agents on different soils /e.g. acid rain, heavy metals, pesticides, excess use of fertilizers, etc./.
8. Study economic ways of preventing adverse soil changes and of regenerating and rehabilitating soils that have undergone degradation.
9. Study the dynamics of soil formation in order to quantify the response time of soil changes as a result of changes in climate, vegetation land use and management.
10. Develop methodologies to observe and monitor soil changes at the macro-level /e.g. through remote sensing/.
11. Develop theory and practice of scalar modeling of land and soil resources.
12. Organize and coordinate the monitoring of soil changes at national and international level.

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