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TRENDS OF WORLD-WIDE SOIL DEGRADATION

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Abstract

Erosion by water and wind, nutrient depletion, chemical pollution, salinisation and soil structural decline represent serious forms of soil degradation in many parts of the world. Soil degradation, in this context, is defined as:" a process which lowers the current and future capacity of soils to produce goods and services". Approximately 15% (~1964 million ha) of the total land surface of the world is degraded as a result of (adverse) human activities. Worldwide, about 38% of the agricultural land is affected by human-induced soil degradation, about 21% of the land under permanent pasture is degraded, and about 18% of forest and woodlands is degraded. Water erosion (56%), wind erosion (28%) and nutrient decline (7%) are the most pronounced forms of degradation. Deforestation, overgrazing, agricultural mismanagement and environmental effects of industry are major causative factors which differ in importance in different areas of the world. In addition to these problems, prime agricultural soils fall victim irreversibly to city expansion and road building.

On the whole, trends in soil degradation in the world are not improving. Effects of climate change and potential freshwater shortages have caught public attention and have led to international agreements and research programs. In contrast, soil degradation is defacto accepted and, generally, not seen as the often irreversible, ecological time-bomb which it really is. How can this be changed? First, people have daily experiences with weather and water while the soil is invisible. Still, people strongly identify with the land they live on and the land where they were born. It is therefore important to show what their soils are like, how they behave in nature and how they are affected by human intervention. This effect is not necessarily bad and positive effects of management by man should, for a change, be stressed next to the adverse effects. Second, the uniqueness of the land (soil and climate) should be stressed in the context of showing the immense diversity of land all over the world. This, in turn, offers unique opportunities. Currently, many of our statistics fail to properly illustrate this diversity. Third, scientific work should be focussed on demonstrating the functioning of the dynamic soil system as expressed by inter-related physical, chemical and biological processes. New techniques, such as simulation modelling, GIS and various monitoring devices, are available now to show what the options are for any given soil in terms of its performance for a wide variety of uses. Modern users of soil information are more interested in learning about their options rather than in receiving absolute judgements as to, for instance, suitabilities for a given use. Fourth, measures should be defined to rate and rank soils. The German "bodenzahl" was excellent as a concept and can now be modernized in terms of soil or land qualities. In the end, such measures are only successful when they are introduced in environmental laws in terms of indicators and threshold values. Soil scientists should make a concentrated effort to lift their work into the public arena.

keywords: soil degradation, international research, human intervention, diversity, modelling

1 Introduction

Water erosion, induced by human intervention, already occurred some 1000-3000 years ago on the loess plateaux of China and in the uplands of the Mediterranean region. As a whole, however, the natural resources for food production have shown a marked deterioration during the last decades. Land has been degraded, water resources have been depleted, desertification and urbanisation have increased, biodiversity has decreased, the global climate is changing, and there have been negative impacts on human health (WATSON *ET AL.*, 1996).

Human-induced soil degradation often is caused by overexploitation of the soil; a situation brought about by poverty, ignorance, and an inability to adopt a sustainable system of agriculture (BRIDGES AND OLDEMAN, 1999). The on-site and off-site effects of land degradation on land resources, soil productivity and the environment are far reaching (Arnold et al., 1990; De Boodt and Gabriels, 1980; Rickson, 1994). Thus soil degradation poses an increasing threat to global natural resources, and the impact of these processes can undermine socio-economic development (E.G., BROWN, 1999; WCED, 1987). Policy measures and conservation methodologies are needed to halt and reverse this trend (e.g., UNCED, 1992). In addition to soil degradation, land is lost when cities expand and when roads are built. Even though areas covered are relatively low when expressed in terms of areal percentages, expansion of cities often occurs in areas with good and accessible soils, thus creating major effects.

In this paper, we shall first review the status, and trends, of human-induced soil degradation in the world. When discussing trends in world-wide soil degradation, we must move beyond defining the magnitude of the problem by also focusing on means to overcome, or, even better, to avoid the problems in the first place. Even though most people have an instinctive affinity with the land where they were born or where they live, they are still largely unaware of the problems associated with soil degradation. So, while climate change and freshwater shortage catch the imagination of the public and politicians alike, soil degradation does not appear to tickle as many nerves. We will, therefore, make an attempt to analyze this phenomenon and to explore possibilities to change this remarkable state of affairs.

2 Global assessment of human-induced soil degradation

Soil is a non-renewable natural resource and difficult to reclaim when degraded. Despite this recognition, the total areas affected by different types of soil degradation were only poorly known until recently. BISWAS and BISWAS (1974), for example, estimated that about 10% of the world's arable land had been destroyed by human activities, without providing specific information about its geographical occurrence. Several groups (DREGNE, 1986; ISSS, 1987) pointed at the need to know where soil degradation is most prevalent, and where the stable lands occur. In response to such queries, the UNEP-sponsored project on Global Assessment of Human-Induced Soil Degradation, GLASOD was implemented at ISRIC.

In GLASOD, soil degradation is defined as “a process that lowers the current and/or future capacity of the soils to produce goods and services” (OLDEMAN *ET AL.*, 1991). The main types of soil degradation considered in this 1:10 million scale study are: (a) water erosion; (b) wind erosion; (c) chemical degradation, including loss of nutrients, salinisation, acidification, and pollution; and, (d) physical deterioration, which includes compaction, sealing and crusting, waterlogging, and subsidence of organic soils. Combined, these various forms of degradation affect about 15% (1964 x 10^6 ha) of the total land surface (between 72 °N and 57 °S; 13,013 x 10^6 ha). Areas not affected, at present, by human-induced soil degradation (45%), stable under natural conditions (28%), and non-used wastelands (11%) are considered as separate categories on the map. The figures for degradation, as shown in Table 1, should be considered to be rough estimates only, but they indicate a clear trend in "global soil degradation".

Table 1: Extent of the status of human-induced soil degradation by type, degree and causative factors for the world and major continents or regions (as 10^6 ha)

	Region							
	Asia	Africa	South America	Central America	North America	Europe	Austral-Asia	World †
Degradation type:								
Water	440	227	123	46	60	115	83	1094
Wind	222	187	42	5	35	42	16	548
Nutrient decline	14	45	68	4	-	3	+	135
Salinisation	53	15	2	2	-	4	1	76
Pollution	2	+	-	+	-	19	-	22
Acidification	4	2	-	-	+	+	-	6
Compaction	10	18	4	+	1	33	2	68
Waterlogging	+	+	4	5	-	1	-	11
Subsidence of	2	-	-	-	-	3	-	5
organic soils	747	494	243	63	96	219	103	1964
Total †								
Degradation degree:								
Light	296	174	105	2	17	61	97	749
Moderate	344	192	11	35	77	144	4	911
Strong	108	124	25	26	1	11	2	296
Extreme	1	5	-	-	-	3	+	9
Causative factors:								
Deforestation	298	67	100	14	4	84	12	579
Overgrazing	197	243	68	9	29	48	83	677
Agric. Mismanage-	204	121	64	28	63	64	8	552
ment	46	63	12	11	-	1	-	133
Over-exploitation	1	+	-	+	+	21	+	23
Industrial activity								

Notes:
+ Area of less than 1 million ha
- Area affected not recognised by local experts
† The sum of individual categories of degradation may differ slightly from those presented by OLDEMAN et al. (1991) due to rounding.

On the GLASOD map, the status of degradation is expressed in terms of its degree and relative extent, which combined give the severity of soil degradation. In the methodology, the (current) degree of soil degradation has been related, in a qualitative manner, to the agricultural suitability of the soil, to its reduced productivity, and to the possibility for restoration to full productivity respectively restoration of the original biotic functions.

Main causative factors of soil degradation have been considered also, with respect to the last 10-25 years. They include deforestation, overgrazing, agricultural mismanagement, over-exploitation, and industrial activity (Table 1). Detailed descriptions of the definitions and criteria used for the expert-based, GLASOD assessment may be found in OLDEMAN et al. (1991).

Globally, water erosion is the most prevalent type of soil degradation (56%), followed by wind erosion (28%), and nutrient decline (7%). Expressed in terms of total area affected, water erosion is most extensive Asia and Africa, followed by South America and Europe. Wind erosion is most important in Asia and Africa. Nutrient decline is particularly important in South America and Africa (SEE SMALING *ET AL.*, 1996), followed by Asia. Salinisation is the most important process of chemical soil degradation in Asia, while soil pollution is important in large parts of Europe. According to the responses of the national experts who provided data for the GLASOD inventory, soil pollution is considered of minor importance in North America. With respect to physical degradation, soil compaction, sealing and crusting are most important in Europe, Africa, and Asia.

Deforestation is considered the predominant causative factor of soil degradation for Asia and South America, but is also important in Europe and Africa. Overgrazing is particularly important in Africa and Asia, followed by Austral-Asia and South America. Negative impacts of agricultural mismanagement are most extensive in Asia and Africa, in terms of total areas affected globally. Environmental effects of industrial activity are most pronounced in Europe, with only minor extents elsewhere, according to the GLASOD inventory.

2.1 Uses of the GLASOD map

The digitised GLASOD map, and the associated GIS-database, has been used to produce a range of statistics (VAN LYNDEN, 1995; WRI, 1992), to provide materials for UNEP's World Atlas of Desertification (MIDDLETON AND THOMAS, 1992; UNEP, 1997) and Europe's Environment Assessment (EEA, 1999). It also provided input for various global modelling studies (ALCAMO et al., 1998; BATJES, 1996; NACHTERGAELE, 2000). BOT *et al.* (2000) presented an overview of land potential and constraints by country, which includes its land degradation status as derived from the GLASOD map. One may question, however, whether the 1:10 million scale of the GLASOD map is appropriate for making the latter type of estimates for individual countries, especially the smaller ones.
By combining statistics from FAO's (1990) production yearbook and data from GLASOD, the global and continental extent of agricultural land, permanent pastures, forest and woodland affected by human-induced soil degradation has been calculated (OLDEMAN, 1994). Table 2 shows 38% of the agricultural land is affected by human-induced soil degradation (which comprise 20% moderately degraded and 6% strongly degraded land). In addition, about 21% of the land under permanent pasture is degraded, of which almost 40% is moderately degraded. With respect to forest and wooldands, about 18% is degraded, of which almost 50% is moderately degraded.

Table 2: Global and continental extent (as 10^6 ha) of agricultural land, permanent pastures, forest and woodland, and percentage affected by human-induced soil degradation (Source: OLDEMAN, 1994)

	Agricultural land			Permanent pasture			Forest and woodland		
	Extent[a]	Degraded	%	Extent[a]	Degraded	%	Extent[a]	Degraded	%
Africa	187	121	65	793	243	31	683	130	19
Asia	536	206	38	978	197	20	1273	344	27
S. America	142	64	45	478	68	14	896	112	13
C. America	38	28	74	94	10	11	66	25	38
N. America	236	63	26	274	29	11	621	4	1
Europe	287	72	25	156	54	35	353	92	26
Oceania	49	8	16	439	84	19	156	12	8
World	1475	562	38	3212	685	21	4048	719	18

[a] **FAO (1990)**

Figure 1 suggests a clear relationship between the severity of land degradation, as considered on the GLASOD map, and population density for selected regions of the globe. For most countries, higher population densities are associated with areas judged to be more intensively degraded (NACHTERGAELE, 2000). However, for some regions/countries one may suspect out-migration from, and even abandonment of, degraded lands, and hence a possible decrease in population density in the worst affected areas. The key issue, however, is that the growing population must be fed and housed, requiring conservation of the natural resources (e.g., World Food Summit held in Rome, November 1996).

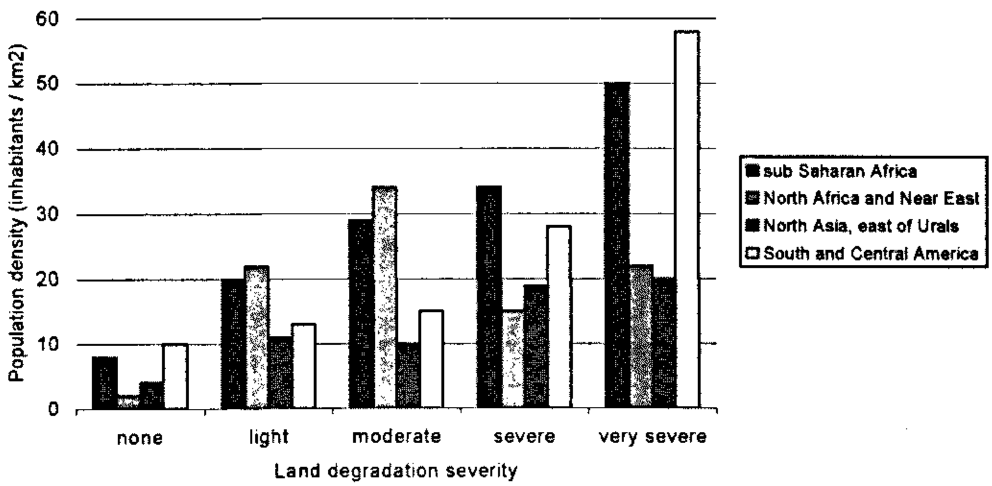

Figure 1: Population density in relation to land degradation severity (Modified after: NACHTERGAELE, 2000).

Since the completion of GLASOD, more detailed studies have been performed for South and South East Asia (ASSOD; see VAN LYNDEN and OLDEMAN, 1997) and for Central and Eastern Europe (SOVEUR; see BATJES, 1999). Both studies consider the possible impact of soil degradation on soil productivity, in qualitative terms. Contrary to the ASSOD study, SOVEUR considers both a soil degradation status and risk component. Complementary to the above type of studies, it is important to identify which remediation techniques can best be adopted in specific agro-ecological regions (see WOCAT, 1998).

3 Creating awareness

Water- and wind erosion are the most important forms of soil degradation and they are quite dramatic in their effect. Soil disappears! In contrast to other forms of chemical and physical degradation, where degradation features can sometimes be removed by leaching, tillage or by stimulating biological activity, after erosion there is nothing left to repair. Given the fact that many papers have been published on soil erosion and on measures to combat the phenomenon, it is surprising to see how little is done in practice to effectively combat erosion processes. It is surprising also to see how difficult it is to fund projects that characterize the status of soil degradation in the world. How, then, to create awareness with citizens, planners and politicians? A number of possibilities are discussed below.

3.1 Demonstrate the unique behavior of different soils and the impact of man

Even though many people have a strong affinity with “the land” they live on, it is a rather abstract affinity. Soils occur in “darkness” below the surface of the earth and, in contrast to weather and water, are not directly visible and cannot be experienced by the senses unless one digs a hole. Attempts have been made to show the composition of different soils by preparing monoliths and by displaying them on the walls of offices, schools and other buildings. In the USA, every State in the Union has a “State Soil”, just like a “State Bird”. This is helpful, but particularly in showing that the vertical composition of soils is quite diverse and beautiful. To really understand the significance of soils, a functional approach is needed which shows their functioning within landscapes, their ability to supply water and nutrients to plants, to support natural vegetation, to purify waste waters that percolate through them, to carry loads etc. These functions determine their crucial value for society. Some measurements or observations are often available to document aspects of the functioning of soils. Yields of crops are often known as are natural vegetation and some important properties such as drainage status and trafficability. But this knowledge is usually limited and descriptive and does no justice to effects of interacting physical, chemical and biological processes which really determine the dynamic character of soils and their functioning in ecosystems. How can this dynamic characterization be achieved?

Use of remote sensing techniques and of proximal sensors is essential to document actual soil processes. However, such techniques are complex and costly and widespread application is therefore unlikely. The advance of computer simulation of soil processes has, however, proved to be quite helpful in documenting the effects of such processes and to demonstrate the impact of man (e.g. ALCAMO, 1999). DROOGERS and BOUMA (1997) studied, for example, a prime agricultural soil in the Netherlands and used simulation of crop growth — as a function of water and weather regimes and nitrogen fertilization scenario's for a period of 15 years — to express the capacity of this particular type of soil to produce a crop under different conditions of water- and nitrogen stress, under the condition that the nitrate content of the groundwater never exceeds environmental threshold values. This way a proxy value for resilience is obtained which, to many, appears as a measure for quality. DROOGERS and BOUMA (1997) compared a soil that had been tilled with conventional methods for 50 years with a soil that had been subjected to biological farming for 60 years, and documented the significant changes in soil behavior that had resulted from these different types of management. Different behavior in terms of nitrification was significant in view of pressing legislation regarding nitrate pollution in groundwater. Simulation, supported by monitoring of test sites, can be used to successfully communicate dynamic behavior of soils as a function of different types of management. HACK et al. (1999) demonstrated that nitrogen application regimes, developed after much research in a well-planned mixed farming system, had quite different effects on different major types of sandy soils in the Netherlands. This observation was useful to show that simply talking about "sand" represents a gross simplification, let alone that talking about "land" in general without any particular specification provides little focus. Use of computer simulation to demonstrate the dynamic behavior of soils as a function of management is much more attractive for the modern soil user than classic soil survey interpretations which list rigid "suitabilities" for a given land use. The modern user wants a range of options to choose from when dealing with land use. He is used to making his own choices and does not like to be presented with single solutions to problems having been developed by others without user-interaction.

3.2 Define measures for the quality of the land

Demonstrating the dynamic behavior of soils may help to improve the general appreciation of soils. Still, the element of communication of essential information to the public and to decision-makers needs special attention in this world suffering from "information fatigue". Other disciplines have learned this lesson. Economists use terms like Gross National Product, inflation rates and many others that are measures for economic quality. The same goes for the social sciences when they present data for childbirth, unemployment, etc. Such measures, or indicators, are not really available for soils yet. Of course, Germany has played a leading role here by developing the "Bodenzahl" in the past and we recommend that this work should be revitalized and modernized.

Our paper cannot cover the complete discussion on soil quality that has developed over the last few years (e.g., DORAN and JONES, 1996; KARLEN et al., 1997; SOJKA and UPCHURCH, 1999). Using simulation techniques for crop growth and water uptake, BOUMA and DROOGERS (1998) and BOUMA et al. (1998a) defined a measure for soil quality based on the ratio between yield and potential yield. Potential yield is determined by climatic conditions and the crop type. The water-limited yield can also be calculated and reflects the natural water supply capacity of the soil, which is often lower that what would be needed when achieving potential growth. The ratio obtained of yield / potential yield, multiplied by 100, allows ranking of soils. BOUMA et al. (1998a) made an exploratory analysis for six major soils of the tropics to indicate effects of different forms of soil degradation on soil quality. The quality measure was effective in showing that effects of different forms of degradation were quite different in different soils. Bouma and Droogers (1998) focussed on the prime agricultural

soil in the Netherlands, as mentioned above. Simulation data were used to indicate the probability that the threshold value for nitrate pollution of groundwater would be exceeded, considering a wide range of fertilization scenarios. Thus, it could be documented that the soil with a biological-dynamic management had the highest quality. The reader is referred to both studies for more details, as these are beyond the scope of this paper.
Definition of soil quality may help to illustrate the importance of the disappearance of prime agricultural land near cities that irreversibly falls victim to city expansion and building of hypermarkets and roads. Cities have often been built originally on sites with good land, and city expansion therefore often leads to loss of relatively highly valuable land. Rather than expand the city, it is advisable to try to revitalise the city centers thereby protecting the land outside the city. Thus, city planners may be natural allies of soil scientists in preserving prime agricultural land, developing pro-active approaches towards planners and politicians.

Concluding remarks

Erosion by water and wind, nutrient decline, salinisation, and compaction remain serious problems in many parts of the world. Pollution of land and water by excessive use of fertilizers and pesticides and by contaminants such as heavy metals, persistent organic pollutants and radionucleides is also widespread (UNEP, 1999). Loss of prime farmland following expansion of cities and building of roads is a real problem which is so far not adequately addressed in a pro-active manner.

Despite the high political recognition of the need for mitigating the adverse impacts of development on the environment (e.g., UNCED, 1992; Tutzing Convention, 1998), surprisingly little attention has been paid to the systematic measurement, compilation, and interpretation of data that could better inform policy- and decision-makers about the appropriate type and scale of possible interventions. While there is clearly scope for improved prediction of land degradation, there are still many problems in the measurement of actual degradation, be it nutrient depletion, soil pollution, or net topsoil loss (e.g., BLUME et al., 1999; BRIDGES et al., 2000), and even more controversy about interpreting the economic and social impacts of that degradation (BROWN, 1999; CUFFARO, 1997; FAO/UNDP/UNEP, 1994). Comprehensive exploratory studies on future land use and consequences of global change can only be realistically pursued when adequate data are being gathered on current land use, degree of soil degradation and contamination, feasible production levels, and water availability (BOUMA et al., 1998b). Available data often are inadequate and do not allow for a satisfactory risk and error analysis to be made.
Even though problems, as described above, are serious, they still receive relatively little attention in research and policy making. An effort should be made to communicate the role of soils in ecosystem functioning in a much more effective manner. Use of modern remote- and proximal sensing techniques can be helpful here, but a particular plea is made in this paper for using simulation modeling to explore the "available options". Definition of soil- or land quality parameters may serve a role here and this aspect needs to be further explored. Of particular concern is the disappearance of prime agricultural land near cities, which can be better addressed when the potential of that land is properly expressed. In addition, an update of the information on global soil degradation, as presented by OLDEMAN et al. (1991), would be useful to identify the main trends (for the last decade), so as to increase overall awareness about the state, driving forces, impacts, and responses to soil degradation.

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