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IMPACT OF SOIL DEGRADATION: A GLOBAL SCENARIO

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1 INTRODUCTION

During the next 50 years the world's population will double (from 5.3 billion people in 1990 to more than 10 billion people by 2050). Cereal deficits in developing countries will continue to decrease from 78 million tons in 1988 to 244 million tons in 2020 even under the most optimistic scenario that food production will continue to grow at the same pace as it has to the present, and that current levels of investments in agriculture by governments will be maintained (IFPRI, 1994).

Although world cereal production almost doubled between 1966 and 1990, the growth in aggregate cereal output started to decline after 1982, mainly as a result of a decline in quality and performance of irrigation systems, an inefficient use of fertilizers, a negative nutrient balance in most non-irrigated drylands in developing countries, increased losses from pests and diseases, and a fall in commodity prices, leading to reduced incentives to invest.

In a report, prepared by a panel of senior scientists for the World Bank, Borlaug (1995) argued that, although advances in science during this century have increased world food supplies more rapidly than the population has grown, "we must acknowledge that in many of the most productive areas – especially irrigated areas located in warm climates – there are problems of declining soil and water quality that, if unchecked, can lead to permanent loss of prime agricultural land. Low profits (mainly in developing countries) have kept farmers from adequately investing in resource conservation, while excessive subsidies (mainly in industrial countries) have caused over-use of agricultural chemicals, with subsequent environmental damage".

In much of Africa and in most non-irrigated dry lands in Asia and Latin America, the mining of soil nutrients is pushing average crop yields into decline. Farmers are trying to produce more food by extending their traditional low-input practices into forest land, or onto drier and more vulnerable pasture lands, or by shortening fallow periods. As a consequence, soil quality deteriorates e.g. by soil nutrient decline, loss of organic matter, and soil compaction. Fertile top soil is washed away by the erosive forces of water, or blown away by wind. This so-called first generation of environmental problems leads not only to a negative nutrient balance, but also causes habitat destruction and loss of bio-diversity.

In some of the more advanced developing countries high-input farming systems have caused a second generation of environmental problems. Excessive use of water in irrigated areas in the semi-arid and arid regions have lead to water-logging and secondary salinization. Excessive use of fertilizers and pesticides and inadequate nutrient and animal waste containment have resulted in acidification and pollution of soil and water resources, not only causing a health hazard for human and animal population, but also leading to loss of bio-diversity and contamination of rivers, lakes and coastal waters.

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The rapidly increasing world population, the increasing deficit in aggregate cereal output, leading to a stagnant per capita food production or even, as is the case in many African countries, to a decline in per capita food production, and the alarming extent of environmental degradation, are the central themes on the international and national agenda's of policy makers, decision makers, and agricultural research organizations.

In his plea for feeding humanity, Pinstrup-Andersen (1995) urged for "Action now to meet the food needs of a growing world population, while preventing or containing environmental degradation". Based on the outcome of a world-wide investigation to map and assess the present status of human-induced soil degradation, coordinated by the International Soil Reference and Information (ISRIC), the former Director-General of FAO stated: "analysis of man-made land degradation raises a fundamental question: Are we going to have enough good land to feed the extra 2.6 billion people who will be on this planet by the Year 2025?" (Saouma, 1994). According to FAO, only 11% of the Earth's surface has no limits on its use for agriculture. Some 28% is too dry; 23% has chemical imbalances; 10% is too wet; 6% is permanently frozen, while on the remaining 22% the soil is too shallow for use as arable land.

According to Scherr and Yadav (1997) land degradation by the Year 2020 may pose a serious threat to food production and rural livelihoods, particularly in the poor and densely populated areas of the developing world. "Appropriate policies are required to encourage land improving investments and better land management if developing countries are to sustainably meet the food needs of their populations".

The soil is a natural resource, which is not renewable in a short time (under most conditions soil is formed at a rate of approximately 1 cm every 100 to 400 years). The soil is very expensive to reclaim or to improve, once it is eroded by water or wind, physically degraded or chemically depleted.

"It is our common duty to safeguard it for future generations, while obtaining the best benefit from its use now" (Stoops and Cheverry, 1992).

2 SOIL DEGRADATION: A GLOBAL VIEW

The Global Assessment of the Status of Human-induced Soil Degradation (GLASOD) was the first world-wide comparative analysis focussing specifically on soil degradation (Oldeman, 1994). The objective of GLASOD was "to strengthen the awareness of policy-makers and decision-makers on the dangers, resulting from inappropriate land and soil management, and leading to a basis for the establishment of priorities for action programmes" (Oldeman, Hakkeling, and Sombroek, 1991).

This global study was published as a world map at an average scale of 1:10 Million and was complemented with statistics on the global and continental extent of the various types of soil degradation – water and wind erosion, chemical degradation and physical degradation – their degree and causative factors. GLASOD aroused world-wide interest and the results have been widely cited in many policy papers (Scherr and Yadav, 1996; FAO, 1993, 1996) and reviewed in several scientific journals (Thomas, 1993; Young, 1993; Gardner, 1995; Bongaarts, 1994; Young, 1999).

World-wide around 1.96 billion hectares are affected by human-induced soil degradation, mainly caused by water and wind erosion (1094 million hectares; 548 million hectares respectively). Chemical degradation accounted for 240 million hectares, mainly nutrient decline (136 million hectares) and secondary salinization (77 million hectares). Physical degradation occurred on 83 million hectares, mainly as a result of compaction, sealing, and crusting.

The degree to which the soil is degraded was related in a qualitative manner to the decreased productivity of the soil and the possibility to restore the soil to its original productivity. Around 300 million hectares is strongly degraded, implying that the soil has virtually lost its productive capacity and is not suitable anymore for use in local farming systems. More than 40% of this strongly degraded land is in Africa and around 36% is located in Asia.

A much larger proportion of the earth surface – over 900 million hectares – has moderately degraded. By definition this terrain is still suitable for use in local farming systems, but exhibits a serious productivity decline. However, it can be restored to its original productive capacity. This category needs the full attention of national governments. If no efforts are undertaken to rehabilitate this land a major portion will further deteriorate to the point where it may become unreclaimable.

A significant portion of the Earth's surface – 750 million hectares – is slightly degraded, characterized by a somewhat decreased productivity, but farmers can restore the terrain to its full productivity by some modification of their management.

World-wide around 560 million hectares of agricultural land has been affected by human-induced soil degradation, or around 38% of the total agricultural land (for Africa alone 65% of the agricultural land is affected, while in Central America almost 75% is affected). Annex 1 illustrates some results of the GLASOD study.

As a sequel to GLASOD a more detailed assessment of the status of human-induced soil degradation was compiled for South and Southeast Asia (ASSOD). At FAO's 21st Regional Conference for Asia and the Pacific (New Delhi, 1992) it was recommended that FAO should find means to strengthen the collection and analysis on land degradation in the Asian-Pacific region FAO. FAO's Asian Network of Problem Soils convened an expert consultation in 1993 (RAPA, 1994). This consultation, with delegates from 15 countries in the region, recommended to prepare ASSOD at a scale of 1:5 Million, based on refined and modified GLASOD methodologies and using as a working base map a physiographic map and database constructed along the lines of the internationally endorsed Soils and Terrain Digital Database (SOTER) approach (Van Engelen and Wen, 1995). The study, commissioned by UNEP to ISRIC, was carried out in close cooperation with national resources institutions in the region (Van Lynden and Oldeman, 1997).

Along the same lines, but with more emphasis on soil pollution, the Mapping of Soil and Terrain Vulnerability for Central and Eastern Europe (SOVEUR) was executed as a two-year project (1997-1999). SOVEUR was signed between FAO and the Government of the Netherlands and implemented in cooperation with ISRIC. This study calls for the compilation of an environmental information system for 13 countries in Central and Eastern Europe, enhancing scientific cooperation between Central and Eastern European countries on issues of soil degradation and pollution. The results will be published in 2000. The main objectives of SOVEUR are to strengthen regional awareness of the significant role soils play in protecting food and water supplies and to demonstrate the need for environmental protection.

While GLASOD, due to its scale limitations, could only provide global and continental estimates of the status of the soils, ASSOD was based on country estimates. Moreover, more emphasis was placed on the apparent impact of soil degradation on food productivity, being discussed in the following section.

3 IMPACT OF SOIL DEGRADATION ON FOOD PRODUCTIVITY

While there is wide-spread evidence that soil losses from water and wind erosion and soil chemical and physical disturbances resulting from mismanagement of the soil and its vegetative cover are far in excess of the natural rate of soil formation processes, the impact of these changes in soil qualities on crop yields or production has not been well-established in physical or economic terms. Science faces the challenge of assessing the impact of soil erosion by water and wind. To what extent is productivity affected? Economic estimates only focussing on production can be misleading because the underlying problem of soil degradation, its long-term irreversible consequences on soil productivity and the urgent need for action to rehabilitate these soils are under-estimated (Hurni, 1996).

Scherr (1999) in her overview whether soil degradation is a threat to developing-country food security by 2020, indicates that data on the effect of degradation on global productivity are necessarily very rough, ranging from 15 to 30% reduction as a result of all the various effects of soil erosion (Pimentel, Allen and Beers, 1993) to not more than 9% average productivity loss on the total area of land in crops and permanent pasture (Crosson, 1997). Scherr concludes that degradation appears not to threaten global food supply by 2020, although the effects of soil degradation on food consumption by the rural poor, agricultural markets, agricultural income, and in some cases, national wealth are significant.

3.1 Impact of soil degradation on food productivity based on GLASOD

Crosson (1994, 1997) used data derived from GLASOD on lightly, moderately, and strongly degraded agricultural and pasture lands and assumed percentage losses of productivity for each degradation category (15%; 35%; 75%). He then arrived at a global productivity loss not higher than 8.9%. Using Crosson's approach, but separating cropland from pasture level and assigning similar productivity losses for cropland, but lower productivity losses for pasture land (5%; 18%; 50%), and estimating these losses for all continents, Oldeman (1998) arrived at a world-wide average percentage cumulative loss of productivity of 12.7% for cropland and 3.8% for pasture land. In Africa however productivity losses for cropland were 25% and for Central America even 36.8% (see Table 1).

Table 1 – Average percentage cumulative loss of productivity during post-war period as a result of human-induced soil degradation, world-wide and per continent.

	Crop land	Pasture land	Crops and Pastures	(Crops and Pastures)
(percentage loss per degradation category (light, moderate, strong)	15, 35, 75	5, 18, 50	5, 18, 50	15, 35, 75
World	12.7	3.8	4.8	8.9
Africa	25.0	6.6	8.1	14.2
Asia	12.8	3.6	4.7	8.9
S. America	13.9	2.2	4.1	6.7
C. America	36.8	3.3	8.7	14.5
N. America	8.8	1.8	3.0	5.8
Europe	7.9	5.6	4.6	9.0
Oceania	3.2	1.1	1.2	3.2

The percentage accumulate loss in food productivity at a world level for crops and pasture land does not seem to be alarming in an economic sense. On the basis of this backward looking approach to estimating the impact of soil degradation on food productivity, Crosson (1997) concluded that nothing that could be feasibly done to deal with degradation is going to contributed much to meeting future global demands for food.

However, two remarks should be made. Firstly it should be realized that the availability of food supplies is not equally distributed worldwide. There are significant differences between continents (see table 1) and the global GLASOD study suggests a critical need for further study to more accurately investigate soil degradation problems at national and sub-national level (WRI, 1992).

Secondly, one may assume that if we do not deal with the causes of soil degradation – and its off-site effects, which are not discussed in this paper – areas now only slightly degraded may become in time moderately degraded, moderately degraded areas become strongly degraded, and strongly degraded areas may go out of production. If the total degraded area of cropland would double in the next 45 years the percentage cumulated losses in food productivity at a world level could become as high as 37%. In this calculation it is assumed that the total area of cropland remains at the present level. There is very little spare land available (Young, 1999). Protection of the undisturbed portion of the land presently cultivated, and rehabilitation of the slightly and moderately degraded land seems to be of utmost importance if we want to meet food demands in 21st century.

3.2 Impact of soil degradation, on food productivity, based on ASSOD

Changes in soil and terrain properties such as loss of topsoil, development of rills and gullies, loss of nutrients may reflect the occurrence and intensity of the process of soil degradation, but not necessarily the seriousness of its impact on food productivity. The removal of a 5 cm layer topsoil may have a serious effect on a shallow soil with a thin topsoil, but may not directly impact the productivity on a deep, fertile soil.

The assessment of yield reduction as a result of soil degradation is also complicated by the fact that farmers may apply increasing amounts of fertilizers to compensate nutrients lost by topsoil erosion or by extracting nutrients from the soil. They may improve tillage practices to ameliorate soil structure when compacted by heavy machinery. Despite these ameliorating management practices, studies in the U.S.A. have shown a relationship between soil erosion and reduced yields on many soils (Batie, 1983). Despite technological innovations to improve the productivity of the soil the average rate of change in total productivity increases has declined from 2.2% annually during 1950-1965 period to 1.8% annually during the period 1965-1979 in the U.S.A. Since soil degradation impacts can be more or less hidden by the effects of various management practices, changes in productivity as a result of soil degradation were assessed in ASSOD in relation to the level of management. Five levels of soil degradation impact were defined (negligible; light; moderate; strong; and extreme). The changes in productivity, estimated over the past 10 to 15 years, were ranged from a large increase, small increase, no increase, small decrease, large decrease, to unproductive. The level of management was split up in three classes: high, medium, low. Table 2 shows how the impact of soil degradation on productivity is related to changes in productivity and the level of management. The figures indicate the areas affected by soil degradation in South and Southeast Asia within each management class.

Table 2 – Impact of human-induced soil degradation on changes in food productivity and areas (in million hectares) affected under different management levels for South and Southeast Asia

Level of productivity change	Level of management					
	High		Medium		Low	
	Impact	Area	Impact	Area	Impact	Area
Large increase	negligible	67	--	--	--	--
Small increase	light	171	negligible	78	--	--
No increase	moderate	82	light	135	negligible	30
Small decrease	strong	41	moderate	74	light	119
Large decrease	extreme	11	strong	51	moderate	69
Unproductive	extreme	0	extreme	--	strong	30
Total area affected: 958		372		338		248

The total land area affected by human-induced soil degradation in South and Southeast Asia is around 960 million hectares. From this area around 18% has a negligible impact, 44% a light impact, 23% a moderate impact and 14% has a strong to extreme impact on food productivity. Although this assessment is qualitative and is based on informed opinion, the results clearly indicate that human-induced soil degradation is a serious problem and has a clear impact on food production.

4 SOIL EROSION RISK AND ITS IMPACT ON FOOD PRODUCTIVITY. FUTURE SCENARIO

While the GLASOD/ASSOD approach reflect the present status of human-induced soil degradation and its impact on food productivity in the recent past ("backward-looking approach"), it is highly important to assess the risks of future soil degradation and its future impact on soil productivity ("forward-looking approach").

As indicated earlier, the impact of soil degradation on the functional properties of land and its productive capacity differs between land units and/or soils. In order to assess future risks of soil degradation under certain defined future management and land use scenarios more precise and quantitative information is needed on soil and terrain attributes, on climatic variables, on present land use and vegetative cover.

The International Union of Soil Science (IUSS), FAO, UNEP, and ISRIC developed an internationally endorsed methodology for the systematic storage of detailed information on soil and terrain resources in such a way that this geographically referenced (GIS-linked) database – the Soil and Terrain Digital Database (SOTER) – can be assessed and combined in order to analyze any combination of land, water, and land use within a country or region from the point of view of potential use, in relation to crop requirements, environmental impact or conservation (Van Engelen and Wen, 1995).

A brief description is given how the impact of simulated soil erosion (*in casu* loss of topsoil) after a period of 20 years on food productivity can be assessed (Mantel and Van Engelen, 1997).

First a qualitative model for physical land evaluation developed in ALES (Automated Land Evaluation System) was linked to a SOTER database to assess the suitability for mechanized, low input wheat. This resulted in a suitability map for wheat (The non-suitable areas were excluded in further quantitative calculations).

Next, the erosion risk was calculated using the SOTER Water Erosion Assessment Program (SWEAP) (Van den Berg and Tempel, 1995). The results are not presented on an absolute scale as soil loss in tons per hectare, but in qualitative terms (erosion hazard units). This allows for a comparison of erosion risk between various areas within a country.

In a subsequent step the potential (bio-physical production ceiling) yield, the water-limited yield and the nutrient-limited yield for each SOTER unit was calculated. The water supply to the plant is determined by the water buffering capacity of the soil, while the nutrient-limited yield is a function of the availability of macro-nutrients in the rooting zone of the soil.

In the next step the soil erosion risk as calculated for the mapping units was used as a basis for calculating a simulated loss of topsoil over a 20-year period. Topsoil losses ranging from 0 to 50 cm over a 20-year period were established for the dominant soils in the mapping units and new input data files were created to recalculate water-limited and nutrient-limited yields. Comparing the yields now and after 20 years erosion gives an indication of the impact of erosion on crop yields. This approach can give an indication on a possible yield decline as a result of water erosion at regional or national level, but more importantly perhaps it gives a spatial impression where soil erosion shows the highest impact. This information can be useful for national land use planning agencies.

The results of this study can be complemented with some statistical trends as illustrated in Table 3. It indicates the areas (as a percentage of the total suitable area for mechanized low input wheat in Uruguay) for each yield class under constraint-free conditions, nutrient limited and water-limited conditions now and after 20 years of simulated water erosion.

Table 3 – Trends in yield under constraint free, nutrient limited (before and after erosion) and water-limited (before and after erosion) conditions expressed as a percentage of the total suitable area for mechanized low-input wheat.

Conditions	Yield classes (in ton/ha)					
	0-0.5	0.5-1.0	1.0-2.0	2.0-3.0	3.0-4.0	4.0-5.0
Constraint-free			30	31	31	9
Nutrient-limited	1	1	34	34	21	8
Nutrient-limited after 20 years of erosion	4	-	34	43	9	8
Water-limited	7	20	43	16	13	2
Water-limited after 20 years of erosion	28	27	42	1	1	1

It can be concluded that the nutrient-limited yield potential is not significantly different from the constraint-free yield, and that the nutrient-limited yield on the generally fertile and organic matter rich soils is little affected by topsoil erosion. The water-limited yield on the other hand is significantly different from the constraint-free yield and the water-limited yield is strongly affected by topsoil erosion. If we set the total wheat production under constraint-free conditions at 100 percent, then the nutrient-limited yield is reduced to 93% before erosion and to 86% after 20 years of erosion. The water-limited yield before erosion is 65% of the constraint-free yield before erosion and is reduced to only 16% after 20 years erosion.

5 CONCLUDING REMARKS

As a consequence of increased population pressure and the scarcity of unreclaimed land, physically and socio-economically suitable for cultivation, there will be increasing pressure on all sectors of society to utilize the existing cultivated areas as efficiently as possible and on a sustainable basis.

To effectively develop and implement programmes on food sufficiency, land use optimalization, bio-diversity conservation and land degradation control, policy-makers require information on the extent and quality of land related potentials and constraints.

There is however a growing concern that natural resources information is underused in decision making by policy makers, extension services, and land users/managers. There is an urgent need for better interaction and communication between land resources information providers and external information users. Existing land and soil classification methodologies with its corresponding jargon are in part responsible for this lack of communication.

With the advent of new information and communication technologies high priority should be given to develop geographically referenced computerized information systems that can collect, store and analyse data on natural and socio-economic resources and that can disseminate in "user-friendly" format information about the range of available options and techniques for different types of soils, climates and farming systems (Scherr and Yadav, 1996).

The 17th World Congress of Soil Science (Bangkok, Thailand, 2002) will have as theme: Soils, Confronting New Realities of the 21st Century". Issues that will be discussed are: 1) The role of soils in food security; 2) the role of soil science to provide new solutions for sustainable use of the land; and 3) the role of soil science to generate soil databases required to drive the tools and techniques of the information age (Sompong Theerawong, 1998). He stated in his address to the participants of the 16th World Congress of Soils: "soil scientists have contributed to feeding and clothing 5.6 billion people today: our challenge is to build on this so that we can do the same to 8 billion people in 2020. The reality however is that we have to do this not only on almost the same amount of land, but also on land, which in many parts of the world is being degraded and is rapidly loosing its productivity".

Support from national government agencies and financial support of the donor community are essential. The Science Academy Summit (Madras, 1996) urged world leaders to revert the global trend of disinvestment in agricultural research and development, convinced that such short-sighted policy can only have tragic results. A national natural resource conservation and enhancement strategy will be fundamental to a national food security system. "High priority must go to combating soil degradation and deforestation and to restore degraded land" (IFPRI, 1996).

The International Soil Reference and Information Centre (ISRIC), as a World Data Center for Soils, has formulated its long-term strategy along the same lines: "Contributing to the challenge of providing sufficient food for the growing world population, while preserving the biophysical potential of natural resources and minimizing environmental degradation".

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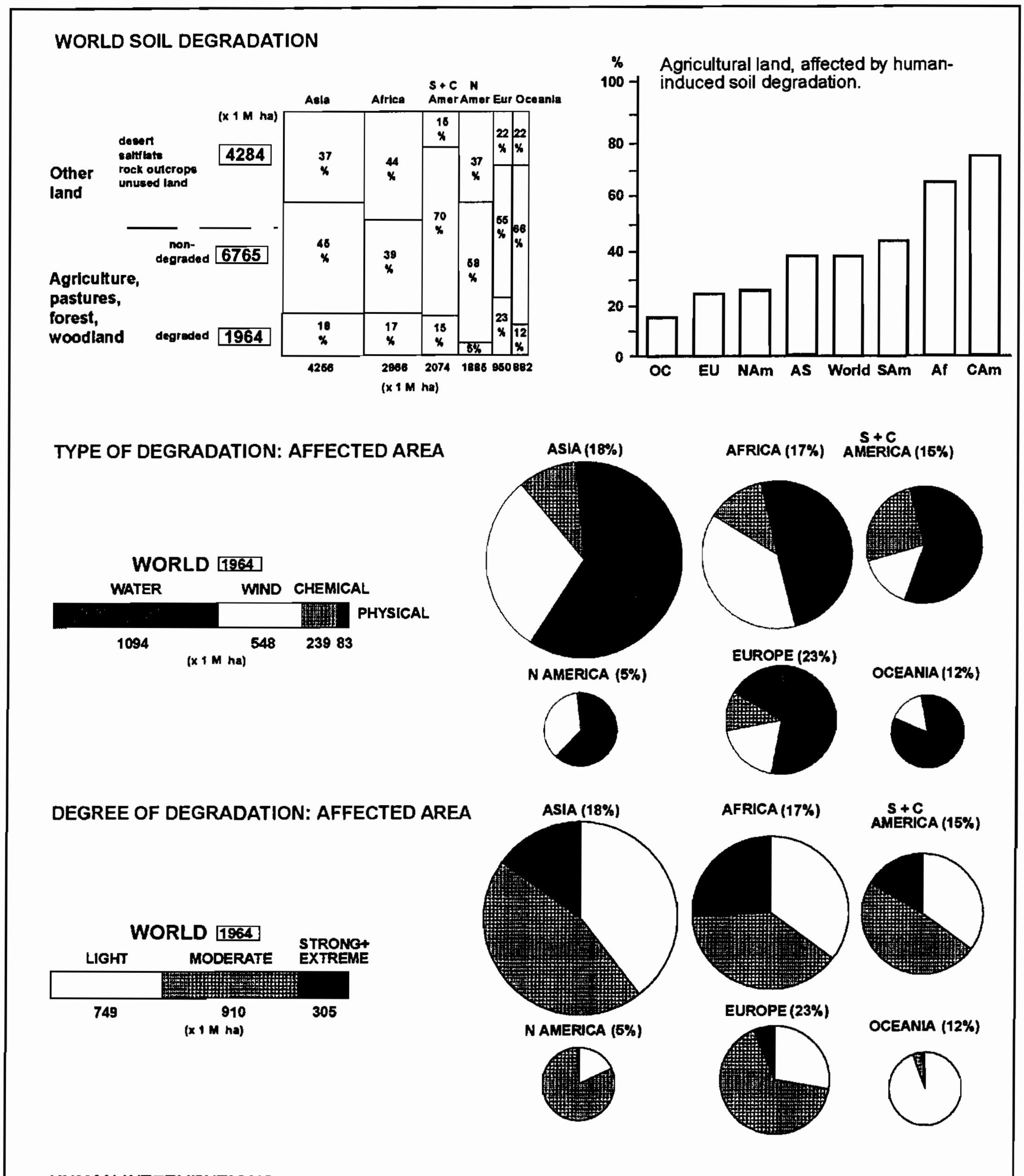
ANNEX 1 – Global Extent of the Status of Human-induced Soil Degradation

Annex



	OVERGRAZING	DEFORESTATION	AGRICULTURAL MISMANAGEMENT	OVER-EXPLOITATION	POLLUTION
AFRICA	243	67	121	63	+
ASIA	198	298	204	46	1
S. AMERICA	98	100	64	12	-
C. AMERICA	9	14	28	11	+
N. AMERICA	29	4	63	-	+
EUROPE	46	84	64	1	21
OCEANIA	83	12	8	-	-

(All data from GLASOD, 1991)