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Soil degradation: a global problem endangering sustainable development

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Abstract: Soil degradation, defined as lowering and losing of soil functions, is becoming more and more serious world wide in recent decades, and poses a threat to agricultural production and terrestrial ecosystem. It is estimated tha t nearly 2 billion ha of soil resources in the world have been degraded, namely approximately 22% of the total cropla nd, pasture, forest, and woodland. Globally, soil erosion, chemical deterioration and physical degradation are the im portant parts amongst various types of soil degradation. As a natural process, soil degradation can be enhanced or da mpened by a variety of human activities such as inappropriate agricultural management, overgrazing, deforestation, et c. Degraded soil means less food. As a result of soil degradation, it is estimated that about 11.9-13.4% of the globa l agricultural supply has been lost in the past five decades. Besides, soil degradation is also associated with off-s ite problems of sedimentation, climate change, watershed functions, and changes in natural habitats leading to loss o f genetic stock and biodiversity. Therefore, it is essential to combat soil degradation at different levels and scale s worldwide, not only for food security and ecological health, but also for the guarantee of global sustainable devel opment.

Soil degradation: a global problem endangering sustainable development CHEN Jie, CHEN Jing-zhang, TAN Man-zhi, GONG Z i-tong (Institute of Soil Science, CAS, Nanjing 210008, China) 1 Introduction Soil is not only the major natural reso urce on which human being depends for the production of food, feed, fiber, renewable energy and raw materials, but al so plays a key role in maintaining the complex terrestrial ecosystems and climate systems of this planet. Recent rapi d increase in the human population is placing a great strain on the world´s soil resources. Only about 11% of the glo bal land surface covered by the soils are being used to raise crops and livestock, in other words, approximately 8.7 billion ha of land worldwide have to feed the 5.9 billion people today (Buringh and Dudal, 1987; Oldeman, 1994; Scher r, 1999) (Figure 1). As a result of intensive agricultural activity and land overuse, soil resource is suffering degr adation of various types. Soil degradation is rapidly emerging as an agricultural and environmental concern of major proportions in recent decades (Scherr, 1999; UNEP, 1997a). Figure 1 Only 11 % of the world´s soils can be farmed with out being irrigated, drained or improved (Source: FAO, 1998) Simply, soil degradation can be defined as measurable l oss or reduction of the current or potential capability of soils to produce plant materials of desired quantity and q uality. Comparatively, land degradation is a broader term, defined as the lowering of the current or potential capabi lity of a land area to serve a desired function, including different uses such as agriculture, transport, constructio n, recreation, etc. (Bluikie and Brookfield, 1987; Blum, 1997; Chisholm and Dumsday, 1987). Soil degradation is signi ficantly increasing the challenge to feed a growing population from a diminishing land area of declining quality, res ulting in food insecurity, agricultural income reduction, and economic slowdown. Besides, it is also associated with off-site problems of sedimentation, carbon emissions affecting climate change, reduced water shed function, and chang es in natural habitats leading to loss of genetic stock and biodiversity (Scherr, 1999; UNEP, 1997b). 2 Types of soi l degradation Soil degradation includes all the processes such as erosion compaction and hard setting, acidificatio n, declining soil organic matter, soil fertility depletion, biological degradation, and soil pollution, etc., which s ignificantly result in decrease of soil quality or soil´s to production capacity in terms of quantity, quality, good s, and other services (Blum, 1997; Lal and Stewart, 1990; Scherr, 1999). According to Esser (1999), soil degradation can be divided into four main facets: erosion (removal of soil materials), depletion (loss of fertility components), accretion (accumulation of harmful chemical components) and compaction (exposure to mechanical stress). In 1991, in p

reparation of the world map on the status of human-induced soil degradation known as the GLASOD (Global Assessment o f Soil Deterioration), a general classification of soil degradation was developed by ISRIC (International Soil Refere nce and Information Centre), in co-operation with FAO and UNEP. In this classification, all forms of soil degradatio n are grouped into four major types, each including several subtypes (Oldeman, 2000) (Table 1). Table 1 Type of soil degradation for GLASOD (after Oldeman, 2000) On the basis of the major degrading forms from which soils suffer in Chi na, the scientists in the Institute of Soil Science, Chinese Academy of Sciences classified soil degradation into 6 m ain types, including erosion, desertification, salinization, pollution, deterioration of soil properties and non-agri cultural uses. Recently, some Chinese soil scientists put forward another classification system of soil degradation a s follows (Huang, 2000; Pan, 2000): Although dominated by one or two major forms, many could be reflected in the degr ading processes of a certain soil. For instance, erosion leads to loss of topsoil rich in nutrients for plant growt h, therefore the soils that suffer degradation caused by erosion can also be considered as undergoing nutrient deplet ion in fact. Furthermore, the contaminated soils by various agrochemicals always have problems of property deteriorat ion. In short, a certain type of soil degradation results from the combination of many negative processes, but one o r more related processes may play a determinative role in shaping the form of degradation. 3 Causative factors of soi l degradation Soil degradation can be described as a natural process that can be enhanced or dampened by human interv ention. Driving forces of soil degradation could be divided into three facets: vulnerability of soils to degradatio n, physical environmental changes and human activities. Vulnerability of soils to degradation is mainly dependent upo n the initial state of the soils such as pedogenetic characteristics, influxes of material, and relative ages. Chemic al, physical, mineralogical, and biological changes which occur in the solum over time make vulnerability of soils va riable rather than constant. For instance, the geologically young soils developed in temperate regions are more ferti le and relatively resistant to degradation than some tropical high land soils formed through the deposition of volcan ic materials from old eruptions, which suffer degradation resulting from leaching of soluble nutrients from columns a nd from acidifying process (Scherr, 1999). Another example comes from soil sensitivity to erosion, showing the soils with a coarse-grained, loose surface horizon has much higher erodibility than those with the surface horizon strippe d away. As mentioned above, soil degradation can be taken as a natural process, just like soil formation. For instanc e, erosion is a geologic process that never stops until land surfaces, including highlands and mountains, have been l eveled to the so-called erosion basis. The physical removal of soil material by water, wind and gravity has been stil l going on even without human activity revolved in. A variety of physical environmental changes including global warm ing, sea-level variation, drought, and earth processes such as geomorphological evolution, volcanic activity, natura l leaching of soils could be causative factors of degradation. Besides, natural hazards such as floods, storms, earth quakes and bushfires etc. can also cause or accelerate soil degradation. The human-induced soil degradation, the so-c alled accelerated degradation, is a much more rapid process compared to the natural degradation. Various types of hum an activities may lead to soil degradation by overuse and misuse of soil resource. According to GLASOD, the main reas ons for soil erosion and chemical soil degradation are agricultural mismanagement, overgrazing and deforestation (Old eman et al., 1991) (Figures 2 and 3). Figure 2 Degradation of the world´s soil resource induced by different human in terventions (after FAO FACTFILE, 1997) Figure 3 Main causes of dryland soil degradation by region (Data source: FAO F ACTFILE, 1997) Since the dawn of settled agriculture, an estimated 430 million ha of productive soil has already bee n destroyed (Kovda, 1983). Poor soil management and inappropriate tillage methods make soils subject to erosion. The rate of global loss of agricultural land due to erosion is about 3 million ha per year (Buringh, 1981). Flood irrigat ion causes accelerated soil acidification and buildup of sodium and other soluble salts, leading to soil salinizatio n and alkalinization. Excessive use of fertilizers, pesticides and herbicides causes toxic accumulations in soil, thu s degrading health quality of soils. Soil compaction is a worldwide problem, especially with adoption of mechanized a griculture, which restricts root growth and movement of water, air, and chemicals. Up to now, over 40% of agricultura l land worldwide is seriously degraded due to intensive human activities. The area of soil resource degraded through agricultural utilization and management amounts to 552 million ha, around 28% of the total degraded soils of the worl d (Table 2). Deforestation includes converting forest into agricultural land, large scale commercial forestry, road c onstruction and destroying forest for other purposes. Deforestation leads to soil degradation by resulting in frequen t erosion and loss of nutrients. Directly resulting from deforestation, the second important causative factor of soi l degradation, 579 million ha of the soils are believed to have significantly degraded worldwide, equal to more than 29% of the total area of the world´s degraded soils. Overgrazing means that actual livestock load exceeds the theoret ical carrying capacity of rangeland. The effect of overgrazing usually is soil compaction and a decrease of plant cov er (or removal of all plant life), both of which may in turn give rise to water or wind erosion. Thereinto, overgrazi

ng is the most important causative force of soil degradation, and has caused the biggest degraded area of about 679 million ha, namely 35% of total area of soil degradation of the world. Table 2 Changes in agricultural land use in the developing world and associated degradation problems (after Scherr, 1999) Besides the causative factors mentioned above, other human activities also induce and accelerate degradation of soil resources. For example, in some cases soil degradation could be regarded as a consequence of industry growth and urbanization expansion. First of all, industrial infrastructure construction and urbanization are often tied to conversion of quality agricultural soils and loss of productive and ecological functions of soils, which can be considered as irreversible degradation of soil resource. Furthermore, mining and industrial activities, improper use of municipal and industrial byproducts can cause build up of excess nutrients and toxic trace elements in soils, thus leading to deterioration of soil quality. 4 Status and impact of soil degradation worldwide In the past 50 years, soil degradation has been accelerated significantly. Up to now it is estimated that nearly 2 billion ha of soil resources in the world have been degraded, namely around 22% of all cropland, pasture, forest, and woodland (Scherr, 1999). According to GLASOD, half of the degraded soil area belongs to moderate degradation. The area of the strong and extreme degradation is more than 300 million ha, almost equivalent to the area of West Europe. Since 1990, losses have continued to mount year by year, with an additional 5 million to 6 million ha which was lost to severe soil degradation annually (UNEP, 1997b; WRI, 2001). Assuming that land loss continues at current rates, an additional 200 million ha would go out of production in the coming 20 years (Figure 4). Figure 4 Global status (degree) of soil degradation (Data source: UNEP/DRID Arendal, 1998) Figure 5 The main types of Human-induced soil degradation of the world (Data source: ISRIC/ENEP/FAO, World food summit, Rome, 1998) Erosion induced by a variety of factors is dominant type of soil degradation worldwide, it occupies about 50% of the world´s land area. Amongst those degraded soils, about 75% of the strongly degraded soils is affected by water erosion. Wind erosion and desertification is the second most important form of soil degradation on all continents except for South America and Europe (instead, chemical deterioration is the second type form for South America, and physical degradation for Europe). Sorting by size of affected area of soil degradation on all continents, they are Asia, Africa, South/Central America, Europe, North America and Oceania (Figure 5). Desertification is soil degradation occurring in the arid areas worldwide. Almost half of the land area of the world consists of drylands and the major part of it is threatened by desertification. Of all the degraded soils in the world, nearly 60% is in drylands. 10 million ha productive land with 24 billion tons of topsoil is lost every year due to desertification (Poulsen, 2001). According to Dregne and Chou (1992), more than 70% of dry lands in Africa, Asia, and South America are degraded. Some 30% of irrigated drylands, 47% of rainfed drylands, and 73% of rangelands are affected by soil degradation to various degrees in the continents. Table 3 Estimated desertified percentages of drylands in Latin America Degraded soil means less food. A continuing increase of the total global food production over the years may attribute to the increased fertilizer use, extension of irrigated lands, and higher cropping densities, which has masked the impact of soil degradation on crop yield (WRI, 2001). It was indicated in Crosson´s study (1994) that soil degradation between 1945 and 1990 had lowered crop production of the world´s 17%. Using the same methods, Oldeman (1998) estimated that soil degradation worldwide had made a loss of 11.9-13.4% of the global agricultural supply in the past five decades. Evidence of significant reduction of soil productivity resulting from soil degradation comes from the available regional studies. The productivity of some soils in Africa has declined by 50% due to soil erosion and desertification. Yield reduction in Africa due to past soil erosion may range from 2% to 40%, with a mean loss of 8.2% for the continent. If accelerated erosion continues unabated, yield reductions by the year 2020 may be 16.5% (Eswaran, 1999; Lal, 1995). In a number of Asian and Middle Eastern countries, several studies indicate that the decline in productivity resulting from soil degradation may exceed 20% (Eswaran, 1999; Lutz et al., 1996; WRI, 2001). A global agricultural model suggests a slight increase in degradation relative to baseline trends could result in 17-30% higher world prices for key food commodities in 2020 (Scherr, 1999). Degraded soil means more cost. In 1992 Dregne and Chou (Scherr, 1999) estimated that soil degradation in drylands worldwide resulted in the cost of $28 billion per year. In Africa, only due to desertification, the financial loss is estimated at over 9 billion US dollars annually (Poulsen, 2001). In South Asia, soil degradation leads to the economic loss of at least US$10 billion annually, equivalent to 2% of the region´s Gross Domestic Product, or 7% of the value of its agricultural output (Khor, 2001). It is estimated that total annual cost of erosion from agriculture in the USA is about $44 billion per year, On a global scale the annual loss of 75 billion tons of soil costs the world about $400 billion per year, or more than $70 per person per year (Eswaran, 1999). Nutrient depletion is another principal process of soil degradation with severe economic impact at a global scale, Pimentel et al. (1993) valued the plant nutrients lost annually just through sediment loss and nitrogen in water runoff at $5 billion, or 0.4% of the annual global value added in agriculture. Table 4 Average cumulative loss of productivity during the p

ost-Second World War period as a result of human-induced soil degradation (Source: Oldeman, 1998; Scherr, 1999) Figur e 6 Percentages of land without soil degradation in China (Data source, IIASA LUC Project, 1998) 5 Soil degradation i n China China is among the areas where the problems of soil degradation are considered to be the most serious. Owing to inadequate systemic and quantitative data, it is quite difficult to figure out accurately the area affected by soi l degradation in China. It was estimated by IIASA (IIASA, 1998) based on the Status of Human-induced Soil Degradatio n in South and Southeast Asia (ASSOD) that 465 million ha of soils had degraded in China, however, 306.9 million ha (or almost 66%) of the degraded land had only a negligible or light degree of degradation (55 million ha of negligibl e, and 252 of million ha of light degradation). Table 5 Soil degradation in China by degradation type according to AS SOD assessment (after Lynden and Oldeman, 1997; IIASA, 1998) Erosion is the important type of degradation in China. D ata from different sources for erosion affecting areas are different. A study from ICRTS (2001) indicates that China has 200 million ha of land affected by erosion, while ASSOD estimates that water erosion affects 180 million ha and s ome Chinese scientists propose 150 million ha (Huang, 2000; Pan, 2000). According to ASSOD, an area of about 200,000 ha has lost topsoil due to water erosion, and 10,000-100,000 ha due to wind erosion, namely, some 6% of the total lan d area of China suffers extreme soil degradation. Annual soil losses in China are estimated at around 5 billion ton s, and the annual losses of soil organic matter, nitrogen, phosphorus and potassium reach some 27 million tons, 5.5 m illion tons, 6,000 tons and 5 million tons respectively. The losses of nutrients of soils resulting from erosion are equivalent respectively to 46%, 2% and 63% of nitrogen, phosphorus and potassium of contents of the annual fertilize r application to cultivated land in China. At present, the total area of cultivated land in China is between 120 and 140 million ha. It is believed that over 60% of cultivated land is affected by some kind of moderate or strong soil d egradations. Besides erosion, chemical and physical forms of degradation are more serious in the major crop areas. I n the early 1990s, 6 millions ha of farmland had suffered pollution originating from industrial and urban wastes. Fur thermore, the related data indicated the area affected by acid rain has expanded to 2.5 million in China in 1994, on e million more than 1985. Rangeland degradation occurs mainly in arid and semi-arid regions. The highest rate of dese rtification is found in areas exploited for both animal husbandry and agriculture. Presently, 67.7 million ha of rang eland are affected by various types and degrees of degradation. It is estimated that desertification has caused the l oss of 42,700 ha of rangeland, equivalent to 3.6% of the entire area of Inner Mongolia. Soil degradation makes soils out of productivity. It is estimated that the annual loss of cultivated land is around 70,000 ha only due to erosio n. With comparison to degradation, industrial activities and urbanization cause much more loss of productive soils i n China. During the period from 1986 to 1995, about 6.7 million ha of arable lands were occupied for non-agricultura l activities, and 75% of these occupied lands were used for urban and industrial infrastructures (Xu and Li, 1999). B esides non-agricultural occupancy of lands, industrial activities and urbanization also cause pollution in the surrou nding soil environment. There is little doubt that China is facing serious soil degradation problems, which is becomi ng a serious threat to sustainable development. Much more effort should be make to combat soil degradation at differe nt levels and scales, not only for the national food security, but for environmental health. References

关键词： soil; soil degradation; erosion; food security; sustainable development

