Impact of land degradation on soil productivity, soil fauna, bio-degradation process and environment

SK Yadav, AK Yadav, KP Ravkar, Ramesh Chandra and Navneet Pareek

Abstract

Land degradation is a major issue of this time because of its adverse impact on soil productivity, human and animal health, soil and water quality on local, regional and global scale. Out of 329 million ha of total geographical area in India, the total degraded area accounts for 120.7 million ha, of which 73.3 million ha is degraded by water erosion, 12.4 million ha by wind erosion, 6.73 million ha by salinity and alkalinity and 25 million ha by soil acidity. Land degradation is of mainly three types such as physical, chemical and biological. Physical degradation refers to the deterioration of the physical properties of soil. Nutrient depletion is a major cause of chemical degradation while reduction in soil organic matter content, decline in biomass carbon and decrease in activity and diversity of soil fauna are ramifications of biological degradation. Thus land degradation has both on site and off site effect on soil productivity. Soil erosion has short-term effect on decline in crop yield and agronomic production and long-term effect decline in soil quality and productivity and nutrient use efficiency of crop. Land degradation decreases soil productivity because of adverse impact on soil physical, chemical and biological properties. Removal of different salts, nutrients, pesticides, herbicides, insecticides through run-off and leaching process and deposition of sediments constitutes environmental pollution.

Keywords: Land degradation, soil properties, soil productivity, organic matter

Introduction

Ever since agriculture was started, land degradation has been the single largest threat to soil productivity and has remained till date. Land degradation will be remain an important global issue for the 21st century because of its adverse impact on soil productivity, soil fauna, bio degradation, environment, and its effect on food security and the quality of life. Productivity impacts of land degradation are due to the decline in land quality on site where degradation occurs, and off site where sediments are deposited. Because in on site land degradation, removal of the topsoil by any means has, through research and historical evidence, and has many deleterious effects on the productive capacity of the soil as well as on ecology. Doran and Parkin (1994) captioned the impact of soil erosion in their popular term that “the thin layer of soil covering the earth’s surface represents the difference between survival and extinction for most terrestrial life.” Although fertile top soils could be lost when scraped by heavy machineries (Ngwu et al., 2005), the key factor of topsoil loss include water erosion and wind erosion.

Loss of soil productivity through soil degrading processes occurs throughout the world. Eswaran et al. (2001) proposed an annual loss of 75 billion tons of soil on a global basis which costs the world about US $400 billion per year. Soil erosion is a symptom of poor soil and crop management and soil erosion by water is the greatest factor limiting soil productivity and impeding agricultural enterprise in the entire humid tropical region (NAP, 1993). Both forms of erosion viz water erosion and wind erosion defines land degradation. In the land degradation phenomena, colloidal fractions are detached and washed away through runoff (Lal et al., 2003). These soil colloidal fractions are needed for soil fertility, aggregation, structural stability, and favorable pore size distribution. The humus content is usually higher in top soils while that of clay is in sub soils due to illuviation, and this is mostly true in Ultisols that are widespread in Africa. This implies that humus, which has much greater capacity to hold water and nutrient ions compared to clay which is more easily eroded during land degradation
process. All the adverse impacts on soil productivity and environmental quality are respectively due to a decline in land quality and deposition of sediments and have been designated on-site effect and off-site effect, respectively (Eswaran et al., 2001) \(^3\). However, the on-site impacts of land degradation on productivity are easily masked due to use of additional inputs and adoption of improved technology and have led some to question the negative effects of desertification.

The relative magnitude of economic losses due to productivity decline versus environmental deterioration also has created a debate. According to economists, the on-site impact of soil erosion and other gradation processes are not severe enough to warrant implementing any action plan at a national or an international level while according to farmers, they should take care of the restorative inputs needed to enhance productivity. Agronomists and soil scientists, on the other hand, argue that land is a non-renewable resource at a human time-scale and some adverse effects of gradation processes on land quality are irreversible, e.g. reduction in effective rooting depth.

Indices of soil productivity affected by land degradation

Soil productivity is the capacity of a soil to produce a definite yield of crops or other plant’s parts under a well-defined conditions and set of management practices. Thus comparison of soil productivity losses to erosion should be done for similar soil and crop management scenarios. Soil productivity entails a balance among soil “physical,” “chemical,” and “biological” properties, as none is of much value without others. All these soil properties are affected mainly by removal of topsoil and crop yields are affected through the resulting changes in these soil properties. There are following ways by which land degradation reduces soil productivity: (i) Removal of plant nutrients in the eroded sediments (ii) Exposure of root-toxic and poorly aerated sub soils (iii) Phosphorus fixation or adsorption in illuviated clay and other Fe and Al containing minerals which makes it the most deficient nutrient in eroded soils (iv) Soil structure deformation leading to surface sealing and crust formation which reduce seedling emergence and infiltration (v) Non-uniform removal of soil within a field which complicates the task of managing the soil to maximize production.

Impact of land degradation

Land degradation affected soil productivity by affecting physical, chemical and biological properties of soil. The impacts of land degradation on physical properties of soil are: (i) Decline in soil structure (ii) Decrease in root zone depth (iii) Increase in crust formation in soil (iv) Increase in soil compaction (v) Increase in gravel content (vi) Altered particle size distribution (vii) Increase in soil strength (viii) High bulk density (ix) Low porosity (x) Lower aggregate stability (xi) Decrease in moisture and nutrient retention capacity (xii) Altered moisture characteristics (xiii) Decrease in saturated hydraulic conductivity (xiv) Decrease in infiltration and percolation rates (xv) Decrease in aeration (xvi) Poor emergence of seedlings The presence of organic matter in the surface soil generally promotes aggregation and may engender a situation where moisture-retaining pores are preponderant in soil. Soil erosion reduces its productivity primarily through the loss of plant available water capacity. Three months after the artificial removal of the top soil at three locations in southern Nigeria, Mbagwu et al. (1984) \(^6\) observed reductions in moisture retention capacity and saturated hydraulic conductivity of the exposed soil layer, which were greater in Ultisols than in Alfisols. Mbagwu and Lal (1985) \(^7\) later reported that limited moisture more than increased compaction caused greater reduction in root growth and dry matter of maize (Zea mays L.) and cowpea (Vigna unguiculata L.) in those locations.

Soil chemical properties affected by land degradation in following ways


In an Alfisol in southwestern Nigeria, Lal (1976) \(^8\) reported that the enrichment ratio (ER; the concentration of plant nutrients in eroded soil materials to that in residual soil) was 2.4 for organic matter, 1.6 for total N, 5.8 for available P, 1.7 for exchangeable K, 1.5 for exchangeable Ca, and 1.2 for exchangeable Mg. For another Alfisol in Central Kenya, (Gachene et al., 2004) \(^9\) recorded an annual soil loss of above 60 tons ha\(^{-1}\) the corresponding values of the ER were 2.1, 1.2, 3.2, 1.5, 1.2, and 1.0, respectively.

Nutrient depletion as a form of land degradation has a severe economic impact at the global scale, especially in sub-Saharan Africa. Stoorvogel et al. (1993) \(^10\) have estimated nutrient balances for 38 countries in sub-Saharan Africa. Annual depletion rates of soil fertility were estimated at 22 kg N, 3 kg P, and 15 kg K ha\(^{-1}\) in Zimbabwe, soil erosion resulted an annual loss of N and P alone totaling US$1.5 billion. In South Asia, the annual economic loss was estimated at US$600 million for nutrient loss by erosion, and US$1,200 million due to soil fertility depletion (Stocking, 1986) \(^11\).

An estimated 950 million ha of salt-affected lands occur in arid and semi-arid regions, nearly 33 per cent of the potentially arable land area of the world. Productivity of irrigated lands is severely threatened by buildup of salt in the root zone. In South Asia, annual economic loss is estimated at US$500 million from water logging, and US$1,500 million due to salinity (UNEP, 1994) \(^12\). Potential and actual economic impact globally is not known. It is not known either for soil acidity and the resultant toxicity of high concentrations of Al and Mn in the root zone, a serious problem in sub-humid and humid regions (Eswaran et al., 1997) \(^13\).

Salinity is considered as one of the most important abiotic stresses, limiting crop production in arid and semi-arid regions, where salt content is naturally high and precipitation can be insufficient for leaching. India has total geographical area of 328.7 million hectare out of which only 142 mha is under agriculture and forestry use. Soil salinity, erosion and land degradation problems not only deteriorate the quality and quantity of crop production but also severely affect the lands and it cannot be further used for cultivation.

Biological properties of soil affected by land degradation are

(i) Reduction in organic matter content due to loss of vegetation from top soil (ii) Reduction in microbial population (iii) Decrease in organic carbon (iv) Reduction in total and biomass carbon (v) Reduction in biomass N, P and S (vi) Reduction in soil respiration rate (vii) Decline in enzyme
activity viz; dehydrogenaze, phosphatase, urease, arylsulphatase etc. (viii) Reduction in microbial activity (ix) Decline in land biodiversity.

Impact of land degradation on soil fauna and bio-degradation process
All these physical, chemical and biological characteristics of soil play an important role in survival of soil fauna or micro-organisms. Mostly micro-organisms or soil animals lives on top soil layers and microbial activity occurs in the layers. Land degradation decreases microbial activity and soil fauna population due to reduction in organic matter content, microbial biomass carbon, microbial biomass N and basal respiration. Consequently the activity of various soil enzymes involve in the cycle of C, N, P and S decreased due to decrease in C turn-over and nutrient availability which results a death of soil fauna and decrease land biodiversity. Bio degradation of organic compounds by soil micro-organisms involves a process known as mineralization whereby microorganisms convert the organic molecules to obtain carbon and energy for growth and multiplication, releasing the inorganic forms of N, P, S or other elements. Thus bio degradation process also depends on soil and microbial population. Land degradation process erodes top soil and harbour of microorganisms which results a reduction in bio degradation process. Although topsoil loss generally has adverse effects on productivity of soils, there can sometimes be an artifact in which case the loss improves soil productivity or at least does not affect it adversely (Wolman, 1985) [14]. This is often as a result of exposure of the surface of a previously buried productive soil following erosion (Meyer et al., 1985) [15].

Effects of land degradation on productivity
Information on the economic impact of land degradation by different processes on a global scale is not available. Some information for local and regional scales is available and has been reviewed by Lal (1998) [16]. In Canada, for example, on-farm effects of land degradation were estimated to range from US$700 to US$915 million in 1984 (Girt, 1986) [17]. The economic impact of land degradation is extremely severe in densely populated South Asia, and sub-Saharan Africa. On plot and field scales, erosion can cause yield reductions of 30 to 90 per cent in some root-restrictive shallow lands of West Africa (Lal, 1987) [18]. Yield reductions of 20 to 40 per cent have been measured for row crops in Ohio (Fahnestock et al., 1995) [19] and elsewhere in mid-west USA (Schumacher et al., 1994) [20]. In the Andean region of Colombia, workers from the University of Hohenheim, Germany (Ruppenthal, 1995) [21] observed severe losses due to accelerated erosion on some lands. Few attempts have been made to assess the global economic impact of erosion. The productivity of some lands in Africa (Dregne, 1990) [22] has declined by 50 per cent as a result of soil erosion and desertification. Yield reduction in Africa (Lal, 1995) [23] due to past soil erosion may range from 2 to 40 per cent with a mean loss of 8.2 per cent for the continent. If accelerated erosion continues unabated, yield reductions by 2020 may be 16.5 per cent. Annual reduction in total production for 1989 due to accelerated erosion was 8.2 million tons for cereals, 9.2 million tons for roots and tubers, and 0.6 million tons for pulses. There are also serious productivity losses caused by erosion in Asia, especially in India, China, Iran, Israel, Jordan, Lebanon, Nepal, and Pakistan (Dregne, 1992) [24]. In South Asia, annual loss in productivity is estimated at 36 million tons of cereal equivalent valued at US$5.400 million by water erosion, and US$1.800 million due to wind erosion (UNEP, 1994) [12]. It is estimated that the total annual cost of erosion from agriculture in the USA is about US$44 billion per year, about US$247 per ha of cropland and pasture. On a global scale the annual loss of 75 billion tons of soil costs (at US$3 per ton of soil for nutrients and US$2 per ton of soil, for water) the world about US$400 billion per year, or approximately US$70 per person per year (Lal, 1998) [16].

Lal (1995) [23] estimated that past erosion in Africa has caused yield reduction of 2-40 per cent and that if present trend continues; the yield reduction by 2020 may be 16.5 per cent. Lal (1995) [23] reported that the decline in maize yield by natural erosion was about 16 times more than that by desurfacing. However, the topsoil is never uniformly removed in one growing season by natural erosion as does desurfacing. Therefore, within the same time scale, the sudden and total disappearance of topsoil due to desurfacing would be expected to result in much stronger changes in soil properties than with natural soil erosion, such that the negative effect of erosion on soil productivity may be exaggerated (Bakker et al., 2004) [25]. In India also land degradation or top soil loss is one of the major factors of low and unstable crops yields in the rain fed semi-arid to sub humid subtropics of India. Vittal et al. (1990) [26] reported that yield responses are up to 2.5 times higher in soils with deeper topsoils when rainfall in the critical period exceeds evapotranspiration than under dried condition in an alfisol. The estimated loss in crop productivity on soils showing different degrees of erosion by water has been shown in table 1. The reduction in yield is significant when the soil depth decreases. The erosion classes may be modified with availability of more data on kind, degree and extent of problem vis-a-vis loss of productivity of different soils. It may also be noted that a moderate water erosion in alluvium derived deep soils may show significantly less reduction in soil productivity as compared with the deep red and black soils (Table 1). Similarly in deep alluvial silty loam soils at Dehradun, each centimeter desurfacing of soil caused 76 Kg ha⁻¹ in maize yield. This reduction is likely to be more severe in shallow soils.

Table 1: Loss of soil productivity due to erosion by water in different soils

<table>
<thead>
<tr>
<th>Soil erosion class</th>
<th>Soil loss (t/ha)</th>
<th>Loss in productivity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Alluvials (Inceptisols)</td>
</tr>
<tr>
<td>Nil to very slight</td>
<td>&lt;5</td>
<td>&lt;5</td>
</tr>
<tr>
<td>Slight</td>
<td>5-10</td>
<td>5-10</td>
</tr>
<tr>
<td>Moderate</td>
<td>10-20</td>
<td>10-25</td>
</tr>
<tr>
<td>Strong</td>
<td>20-40</td>
<td>25-50</td>
</tr>
<tr>
<td>Severe</td>
<td>&gt;40</td>
<td>&gt;50</td>
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</table>

It is in the context of these global economic and environmental impacts of land degradation, and numerous functions of value to humans that land degradation, desertification, and resilience concepts are relevant. They are also important in developing technologies for reversing land degradation trends and mitigating the greenhouse effect through land and ecosystem restoration. As land resources are essentially non-renewable, it is necessary to adopt a positive approach to sustainable management of these finite resources.

Loss of biodiversity
Loss of biodiversity is one of the major global concerns today. India’s biodiversity is unique in the world. As many as
45,000 species of wild plants and over 77,000 of wild animals have been recorded, which comprise 6.5 per cent of the world’s known wildlife. An assessment of the loss of wildlife habitat in tropical Asia in 1986 showed that the country had only 615,095 km² out of original wildlife habitat of 3,017,009 km²; i.e. loss of 20 per cent. Loss of seeds and propagules in the erosion fluxes, washing away of nutrients and run-offs deplete the biodiversity. During the past few decades, India has lost at least half of its forest, has polluted over 70 per cent of its water-bodies and has degraded most of its coasts. The land biodiversity comprises important concerns related to eutrophication of surface water, contamination of groundwater, and emissions of trace gases (CO₂, CH₄, N₂O, NO₃) from terrestrial/aquatic ecosystems to the atmosphere. Soil structure is the important property that affects all three degradative processes. Thus, land degradation is a biophysical process driven by socioeconomic and political causes.

Environmental pollution or environment degradation

Environmental degradation is a result of socio-economic, technological and institutional activities. This degradation occurs when earth’s natural resources are depleted due to land degradation or top soil loss. The resources which are depleted include: (i) Water (ii) Air and (iii) Soil. The degradation of land also impacts our (i) Wildlife (ii) Plants (iii) Animals and (iv) Micro-organisms. Besides it, the major effects on environmental degradation are: (i) Water pollution and water scarcity (ii) Air pollution (iii) Solid and hazardous wastes (iv) Soil degradation (v) Deforestation (vi) Loss of biodiversity (vii) Atmospheric changes

- “ Accumulation of greenhouse gases in the atmosphere including carbon dioxide is tied to rising and extreme change in temperatures and more severe storms”
- “The sea level has raised to 10-20 centi metre, largely as a result of melting ice masses and the expansion of oceans linked to regional and global warming”
- “Small island nations and low-lying cities and farming areas face severe flooding” - UNFDP

Land degradation or top soil loss removes nutrients from the field through runoff and subsurface lateral flow towards streams and rivers, and by leaching to groundwater and pollute water. Land degradation also causes deposition of sediment. Sediment is one of the major pollutants. In India the situation is still worse, since the sediment load from agricultural lands not only continues unabated, but is also on the increase due to the fast rate of our developmental activities. If erosion continues unchecked at its present rate, we shall be left with the reclamation of soil rather than its conservation and management.

Conclusion

Thus it can be concluded that land degradation has both on site and off site effect on soil productivity. Soil erosion has short-term effect on decline in crop yield and agronomic production and long-term effect decline in soil quality and productivity and nutrient use efficiency of crop. Land degradation decreases soil productivity because of adverse impact on soil physical, chemical and biological properties. Land degradation decreases microbial activity and soil fauna population due to reduction in organic matter, microbial biomass carbon, microbial biomass N, basal respiration and activity of soil enzymes involve in the cycle of C, N, P and S. Removal of different salts, nutrients, pesticides, herbicides, insecticides through run-off and leaching process and deposition of sediments constitutes environmental pollution.

References