

A REVIEW OF SOIL DEGRADATION: TYPES AND STRATEGIES FOR REHABILITATING SEVERELY DEGRADED SOILS

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Abstract

Land degradation is a common problem in Nigeria, Africa and the world. Land degradation has adverse effects not only on soils but also on the socio-cultural environment and ecological setting. The major causes include rapid population increase, severe soil loss, deforestation, low vegetative cover and unbalanced crop and livestock production. In addition, topography, soil types and agro-ecological parameters are contributing factors in the degradation processes influenced by man. To control land degradation, conservation measures throughout history are mainly focused on physical conservation structures which have less contribution for the addition of nutrients removed and to control soil erosion as compared to vegetation measures. Land degradation can be prevented through different mechanisms depending on the nature and form of degradation.

Keywords: Soil Degradation, Rehabilitation, Food production

Introduction

Degradation refers to the biological or chemical transformation of the contaminant to a different form with properties distinct from those of the contaminant prior to transformation. Land degradation was a significant global issue during the 20th century and remains of high importance in the 21st century as it affects the environment, agronomic productivity, food security, and quality of life (Eswaran *et al.* 2001). Land degradation includes all process that diminishes the capacity of land resources to perform essential functions and services in ecosystems (Hurni *et al.*, 2010). Soil degradative processes include the loss of topsoil by the action of water or wind, chemical deterioration such as nutrient depletion, physical degradation such as compaction, and biological deterioration of natural resources including the reduction of soil biodiversity (Lal 2001). Simply put, soil degradation is reduction in soil productive quality. Soil degradation is the decline in soil quality or reduction in its productivity. Soil degradation, mostly human induced, is potentially a more critical problem. Increasing population pressure, cultivation of the marginal agro-ecological environment susceptible to various types of land degradation and inappropriate soil management are resulting in serious soil productivity decline, especially under extensive farming practices (Philip and Adam, 2015).

In Nigeria, human-induced soil degradation is a common phenomenon. Its severity is very high for 37.5% of the area (342,917 km²), low for 4.3% (39,440 km²), moderate for 26.3% (240,495 km²), and high for 27.9% (255,167 km²) (United Nations Food and Agriculture Organization 2005). Soil erosion is the most widespread type of soil degradation in the country and has been recognized for a long time as a serious problem (Stamp 1938). In 1989, 693,000 km² were already characterized by runoff-induced soil loss in the south and 231,000 km² were degraded, mainly by wind erosion, in the north. Sheet erosion dominates all over the country, whereas rill and gully erosion are common in the eastern part and along rivers in northern Nigeria (Ologe 1988; Igbozurike 1989).

Redistribution of soil by erosion and deposition is the result of perturbation and a natural landscape-forming process. However, it has been greatly accelerated by human activities in recent decades as the traditional shifting cultivation system has been replaced by more intensive but generally unstable cropping systems (Lal 1993a). The main reason for the land use intensification was and still is the increase in food production required to feed the rapidly growing population. For example, the Nigerian population has increased from 115 million in 1991 to 160 million in 2006 (Federal Republic of Nigeria 2007).

Soil degradation and desertification are already severe issues in sub-saharan Africa (SSA), where smaller size and resource poor farmers follow extractive farming practices. Soil depletion and erosion thus, constitute a hazard whose containment is a prerequisite for national development, particularly in societies that are agriculture-based. In many SSA, fallow periods are being reduced considerably and farmers are increasingly cultivating marginal lands susceptible to various forms of degradation. This is manifested by declining yields, decreasing vegetation covers, salinization and fertility decline and increasing erosion (Philip and Adam, 2015).

The expansion of agriculture into marginal areas, deforestation, the shortening or elimination of fallows, inappropriate farming practices, and low input inevitably have several environmental and economic impacts, especially in sub-Saharan Africa where the resilience ability of the soil is limited (Lal 1995a). This expansion of agriculture causes on-site degradation of natural resources and productivity decline. For example, Mbagwu *et al.*, (1984) observed that soil erosion causes a yield reduction of about 30% to 90% in some root-restrictive shallow lands of southern Nigeria. Off-site problems, such as the siltation of reservoirs, are also common consequences of soil loss. Hence, low agricultural production, food insecurity, low income of the rural

population, and poverty are some consequences of soil erosion. Avoidance of soil loss by improved management and the conservation of natural resources is therefore important to maintain the functions of the soil and contribute to food security today and for future generations (Ehui and Pender 2005). This paper is aim at reviewing soil degradation, types and strategies for rehabilitating severely degraded soils.

Factors of Soil Degradation

Water and wind erosion are two main agents that degrade soils. Water erosion affects nearly 1,100 million hectares (Mha) worldwide, representing about 56% of the total degraded land while wind erosion affects about 28% of the total degraded land area (Oldeman, 1994). Runoff washes away the soil particles from sloping and bare lands while wind blows away loose and detached soil particles from flat and unprotected lands. Another important pathway of soil redistribution, often overlooked, is the tillage erosion caused by plowing, which gradually moves soil down slope in plowed fields with adverse on-site effects on crop production. Soil compaction, poor drainage, acidification, alkalization and salinization are other processes that also degrade soils in specific conditions of parent material, climate, terrain, and water management. These agents and processes are summarized in tables 1 and 2.

Table 1: Factors/agents of Soil Degradation

Agricultural Activities	Industrial Activities	Urbanization
Deforestation	Waste disposal	Conversion of land to non-agricultural use
Excessive ploughing	Acid rain	High population density
Intensive row cropping (monoculture)	Oil spillage	City waste application
Indiscriminate and excessive use of chemicals		
Excessive grazing/high stocking density		
Residue removal		
Irrigation		

Processes (actions and interactions) of Soil Degradation

The table below summarizes the processes of soil degradation

Table 2: Processes of soil degradation

	Physical	Chemical	Biological
A	Soil structure deterioration (root limitation) Compaction Crusting Accelerated erosion Hard setting	Leaching Fertility depletion Laterization Sodification Salinization Toxicity (Al^{3+} , Mn^{2+} heavy metals)	Decline in biomass carbon Reduction in soil organic matter content Decrease population of soil fauna and flora Alteration in biological process favourable to unfavourable.
B	Imbalance in water – air ratios Wetness Drought		
C	Extreme of temperatures Supra optimal Sub optimal		

Types of Soil Degradation

Soil degradative processes include the loss of topsoil by the action of water or wind, chemical deterioration such as nutrient depletion, physical degradation such as compaction, and biological deterioration of natural resources including the reduction of soil biodiversity (Lal 2001). The various types of soil degradation include, but not limited to, soil erosion, soil compaction, low organic matter, loss of soil structure, poor internal drainage, salinization, and soil acidity problems.

i. Soil erosion

Erosion is the process of detachment, transportation and deposition of soil particles by water, wind and other agents. There are two main types of erosion: geologic and accelerated erosion. Geologic erosion is a normal process of weathering that generally occurs at low rates in all soils as part of the natural soil-forming processes. It occurs over long geologic time horizons and is not influenced by human activity. The wearing away of rocks and formation of soil profiles are processes affected by the slow but continuous geologic erosion. Indeed, low rates of erosion are

essential to the formation of soil. In contrast, soil erosion becomes a major concern when the rate of erosion exceeds ascertain threshold level and becomes rapid, known as accelerated erosion. This type of erosion is triggered by anthropogenic causes such as deforestation, slash-and-burn agriculture, intensive plowing, intensive and uncontrolled grazing, and biomass burning (Lal, 2001).

A number of changes in physical, chemical, and biological processes occur due to the accelerated soil erosion (Table 3). These processes rarely occur individually but in interaction with one another (Eswaran *et al.*, 2001). For example, compact soils are more prone to structural deterioration (physical process), salinization (chemical process), and reduced microbial activity (biological process) than un-compacted soils. Some processes are more dominant in one soil than in another. Salinization is often more severe in irrigated lands with poor internal drainage than in well-drained soils of favorable structure.

Table 3: Erosion – induced soil degradation processes

Physical Processes	Chemical Processes	Biological Processes
Increase in: <ul style="list-style-type: none"> • Surface sealing • Crusting • Compaction • Deflocculation • Sand content Decrease in: <ul style="list-style-type: none"> • Topsoil depth • Soil structural stability • Macroporosity • Plant available water capacity • Water infiltration 	Increase in: <ul style="list-style-type: none"> • Acidification • Salinization • Sodication • Water pollution Decrease in: <ul style="list-style-type: none"> • Cation exchange capacity • Nutrient storage and cycling • Biogeochemical cycles 	Decrease in: <ul style="list-style-type: none"> • Biomass production • Soil organic matter content • Nutrient content and cycling • Microbial biomass, activity, and diversity Increase in: <ul style="list-style-type: none"> • Organic matter decomposition • Eutrophication • Hypoxia • Emission of greenhouse gases

(After Lal, 2001)

ii. **Pollution/waste**

Pollution from (metal) mining and processing: Pollution from toxic elements is association with various aspects of mining and processing industries. Mining produces ore as a product along with a considerable amount of metal-contaminated wastes pollution around **iii.** mines is caused by dumping of contaminated overburden, excavating wastes etc.

Waste is any plastics, paper, glass, metal, foods, chemicals, wood, oil, soil, effluents, liquids that have been discarded. How the waste gets generated is from commercial, household and industrial sources. Sewage sludge is another source. Domestic and municipal waste is generated by the consumption of goods, manufacturing, sewage treatment, agriculture, the production and disposal of hazardous substances and construction. They are essential parts of the process of production as the emission of carbon dioxide by human is part of breathing process. From time immemorial, waste disposal has been a problem, and after industrialization the problem has only compounded. This is common all over the state

Types of Wastes

There are basically three types of wastes generated and they are classified based on their chemical, biological and physical characteristics viz:

a) Solid wastes include materials like mining wastes and industrial wastes besides household garbage.

b) Liquid wastes are those in which the composition of solids is less than 1% and there is a high concentration of metals and salts.

c) Sludge contains a mixture of solid and water.

Compaction

Soil compaction is the process by which the soil grains are rearranged to decrease void space thereby increasing the bulk density. Soil compaction adversely affects soil physical fertility, through increasing soil bulk density, decreasing porosity, increasing soil strength, decreasing soil water infiltration, and water holding capacity.

Soil compaction is emerging as a serious problem affecting the yield of field crops leading to soil degradation worldwide. Compaction-induced soil degradation affects about 68 million hectares of land globally (Flowers and Lal, 1998). Soil compaction is the compression of soil by external forces that decrease the volume of pore space while increasing the soil density. It is a densification and reduction in porosity, associated with changes to the soil structure and an increase in strength and a reduction in hydraulic conductivity (Soane and van Ouwerkerk 1994). A thick compacted layer builds up in the root zone as a consequence of poor tillage practices, primarily as a result of the farmer failing to vary the depth of ploughing over several years

(Tursic *et al.*, 2008). The extent of the soil compaction problem is a function of soil type and water content, vehicle weight, speed, ground contact pressure and number of passes, and their interactions with cropping frequency and farming practices (Larson *et al.*, 1994; Chamen *et al.*, 2003). Soil compaction occurs when soil particles are pressed together, reducing pore space between them (DeJong-Hughes, 2001). The existence of high plough sole density layer of 5-15cm thickness at 10-40 cm soil depth in agricultural soils was reported by Sidhu (1980) and particularly in extensively puddled soils with rice cultivation (Sidhu, 1980; Sur *et al.*, 1980; Sharma and De Datta, 1986). Puddling is the process of tilling the soil at high moisture content, causing shear and compression of soil particle (Singh, 1961). It destroys soil aggregates and peds, create plastic mud, and thus eliminates most macropores, which transmit water, remaining macropores are filled by dispersed fine particles (Sharma and De Datta, 1986; Adachi, 1990). Puddling also results in non-linear reduction in water flux through soil (Sharma and Bhagat, 1993).

iv. Fertility Depletion

Nutrient depletion or nutrient mining means net loss of plant nutrients from the soil or production system due to a negative balance between nutrient inputs and outputs. Typical channels of nutrient depletion are nutrient removal through harvest, leaching, denitrification, fire, soil erosion, and runoff. Soil fertility depletion is seen as the most important process in the land degradation equation, and as the main biophysical limiting factor for rising per capita food production in the majority of African small farms (Mokwunye, 1996; Sanchez *et al.*, 1997). For the nation per se, whose livelihood is dependent mostly on agriculture, unchecked soil fertility decline poses a major threat to economic development. Even in the Sahelian area, it is often the supply of nutrients that limits productivity and not the water supply (Penning de Vries and Djiteye, 1982).

v. Low organic matter and soil microorganism

Most tropical soils are highly weathered, highly leached, erodible and low in cation exchange capacity and nutrient reserve. Soil organic matter constitute largely less than 5%, except in forest lands, but play significant roles in the productivity of tropical soils. The roles of soil organic matter include: Supply of plant

nutrients – N, P, S, micronutrients etc – in balanced proportion, Nutrient retention, Soil pH buffer, Binding agent for structural aggregation of the soil, Water retention and Immobilization of toxic elements, heavy metals, and pesticides

Soil biota (living things in the soil, soil organisms) consists of two broad categories – flora and fauna. Soil organisms are a major factor in soil formation and their effects determine many differences between soils. Soil organisms are an integral part of agricultural ecosystems. The presence of a range of a diverse community of soil organisms is essential for the maintenance of productive soils. Soil organisms are responsible for a range of ecological functions and ecosystem services including: nutrient cycling and nitrogen fixation, control of pest and diseases, organic matter decomposition and carbon sequestration, maintenance of a good soil structure for plant growth and rainwater infiltration, and detoxification of contaminants.

Various soil organisms affect certain soil processes in different ways. An excessive reduction in soil biodiversity, especially the loss of species with key functions, may result in severe effects including the long-term degradation of soil and the loss of agricultural productive capacity.

vi. Loss of soil structure

vii. Salinization

It is the process of accumulation of salts, such as sulphates and chlorides of calcium, magnesium, sodium and potassium, in soils in the form of a salty (salic) horizon. It is quite common in arid and semi arid regions. It may also take place through capillary rise of saline ground water and by inundation with seawater in marine and coastal soils. Salt accumulation may also result from irrigation or seepage in areas of impeded drainage.

Strategies for Rehabilitating Severely Degraded Soils

Research on soil conservation has been conducted for many years in Sub-Saharan Africa and in Nigeria (Lal 1976a, 1990). Initiatives have resulted in various so-called on-farm strategies including agronomic measures, soil management, and mechanical methods, as well as off-farm strategies, including mechanical or biological soil conservation technologies.

Physical (structure) can be rehabilitated through maintaining soil organic

matter at high level, enhancing faunal activity and soil restorative farming system compatible tillage method.

Soil Fertility can be improved by balance nutrient application, inorganic and organic fertilizer combination, nutrient recycling through multiple purpose species and agroforestry.

Biological quality can be enhanced by improving micro environment for species (fauna), ensuring food availability and diversity for microbial organisms

Land degradation can be prevented through different mechanisms depending up on the nature and form of degradation. Most types of soil degradation can be prevented or reversed by adding nutrients to nutrient depleted soil, rebuilding topsoil through soil amendments, reestablishing vegetation, or buffering soil acidity (Scherr and Yadav 1996). However, some aspects of land degradation are less easily reversed than others. For example, terrain deformation by gully erosion, or total topsoil loss from erosion, or the wiping out of native soil fauna is more irreversible than a negative nutrient balance, or surface sealing and crusting (Coxhead and Ygard 2008). In parallel, Scherr and Yadav (1996) illustrated that some types of land degradation are, for all practical purposes, irreversible. Examples are severe gulling and advanced salinization. Displacement of soil material (erosion) is also irreversible, although its long-term effects on productive capacity depend on the depth and quality of soil remaining.

According to Coxhead and Ygard (2008), the main environmental principles for reducing land degradation are to maximize vegetation

cover to prevent erosion, replace nutrients removed, and to put in place structures (terraces, bunds, vegetation strips) so as to reduce the speed and volumes of water flow over the soil. From this perspective, tree crops, perennial crops, intercropping and reduced-tillage systems are preferred. Similarly, UNCCD (2004) revealed that forests and tree cover combat land degradation and desertification by stabilizing soils, reducing water and wind erosion and maintaining nutrient cycling in soils. Therefore, sustainable use of goods and services from forest ecosystems and the development of agro forestry systems can contribute to poverty reduction, making the rural poor less vulnerable to the impacts of land degradation.

Broadly speaking, land degradation can be controlled, reduced or even reverted if the land is used wisely, if all functions of the land are taken into account, and if long-term interests of all segments of human kinds replace short-term vested interests of privileged group globally, naturally and locally (Getachew 2005). Scherr and Yadav (1996) also pointed out that rehabilitating degraded landscapes depend on the costs relative to the value of output or environmental benefits expected. Throughout history, efforts to combat land degradation focused on physical conservation structures (Woldeamlak 2003). Similarly, Temesgen *et al.* (2014c) reported that farmers heavily depend on physical soil conservation structures. However, using of vegetative measures is very much limited. However, it is agreed that, land degradation should be treated according to the type of land degradation (Table 4).

Table 4: Components of degradation, type of degradation and ways of improving degraded land (Scheer and Yadav, 1996).

Component	Degradation	Improvement
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Physical soil management	Crusting Compaction Sealing Water erosion Wind erosion Devegetation Over tillage	Soil conservation barriers Terracing Revegetation of denuded lands Tree protection Soil decomposition Breaking up of pans Cover crops Soil deposition Improved tillage methods
Soil water management	impeded drainage Water logging Reduced water holding capacity Reduced infiltration Salinization	Irrigation Water harvesting Field drainage Draining of water logging areas Filter strips
Soil nutrient and organic matter management	Alkalinization Acidification Nutrient leaching Removal of organic matter Burning of vegetative residues Nutrient depletion	Fertilization Composting Green manuring Animal manuring Flushing of saline alkaline soils Liming acid soils
Soil biology management	Over application of agrochemicals Industrial contamination	Introduction of biotic organisms Nitrogen fixing micro organisms
Vegetative management	Decline in vegetative cover Decline in biodiversity Decline in species composition Decline in availability of valued species	Increased vegetation cover Increased species biodiversity Improved species composition Improved availability of valued species

Conclusion

Being a common problem in Nigeria, Africa and the world over, land degradation puts disastrous impact on the socio-cultural environment and ecological setting. The major causes include rapid population increase, severe soil loss, deforestation, low vegetative cover and unbalanced crop and livestock production. In addition, topography, soil types and agro-ecological parameters are contributing factors in the degradation processes influenced by man. To control land

degradation, conservation measures throughout history are mainly focused on physical conservation structures which have less contribution for the addition of nutrients removed and to control soil erosion as compared to vegetation measures. However, as can be indicated in main text, land degradation can be prevented through different mechanisms depending on the nature and form of degradation.

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