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Management Approaches for Revitalizing Physically Degraded Soils

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Abstract

Soil degradation is a serious environmental issue that affects agricultural productivity, ecosystem stability and food safety globally. It refers to the decline in soil health that reduces its ability to perform essential ecosystem functions. Physical soil degradation is particularly substantial as it directly impacts soil structure, porosity, water infiltration, aeration and root growth. Processes such as coalescence, slaking, dispersion, aggregate breakdown and consolidation were responsible for weakening soil structure and its stability. Technologies like remote sensing and GIS further support effective monitoring and management. Strategies like integrated conservation and improved land management are important for restoring soil health and ensuring environmental sustainability.

Keywords: GIS, Organic matter, Soil degradation, Soil structure

Introduction

Soil degradation is considered as major ecological challenge which reduces agricultural production, food safety and ecosystem sustainability worldwide. It is also responsible for the declining soil health and its capacity to provide essential ecosystem due to physical, chemical and biological deterioration (Eswaran *et al.*, 2001). Globally, around 2 billion hectares of land were affected by degradation which causes serious economic and ecological losses. In India, around 97.8 million hectares of land is degraded, nearly about 29.7% of the geographical area dominating in the states Rajasthan, Gujarat, Maharashtra and Karnataka. Among all types of physical degradation soil compaction is a worldwide problem which alone causes around 25-50% yield reductions in some regions of Europe and North America and 40-90% in some parts of West Africa. Whereas, wind erosion is another principal which affects an estimated 9-11 million hectares of Indian land, removing away fertile topsoil (Osman, 2014).

Physical soil degradation considered as most important type of degradation because it directly responsible for affecting the soil structure, soil porosity, water movement and root growth. There are majorly many types of physical degradation among them most dominating are soil compaction, soil erosion through water and wind, soil crusting and sealing, water-logging and structural decline, all of these types majorly affect soil productivity and sustainability. Throughout the globe and in India itself water erosion is considered to be most dominant form of degradation, especially in hilly and intensively cultivated regions of the country whereas, wind erosion considered to be dominant in the regions like arid and semi-arid, according to (ISRIC) International Soil Reference and Information Centre, Wageningen.

The increase in soil degradation needs to be managed for sustainable soil management practices and restoration strategies to sustain agricultural productivity and environmental health.

Mechanisms and Causes of Physical Soil Degradation

Physical soil degradation occurs through various processes which damage soil structure, reduce porosity and restrict water movement and root growth. These mechanisms are coalescence, where fine particles bind soil into dense masses; slaking, where aggregates break apart upon rapid wetting; dispersion, caused by high-level sodium leading to clay particle separation; consolidation, caused by soil compaction from heavy machineries or over-tillage practices;

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and aggregate pulverization, where improper tillage breakdowns aggregates into fine powder. These processes cause various effects on soil by reducing infiltration rate, increasing soil erosion and lowering the soil productivity (FAO, 2015).

Soil degradation majorly causes by natural and human-induced factors. These factors are responsible for damaging soil health and productivity. Natural causes can be occurred through heavy rainfall, droughts, floods, strong winds and steep slopes, by all of these factors the erosion increases and soil structure decline. Climate change is also an important factor which is responsible for soil degradation as increase in temperature and irregular rainfall patterns are one of the major drawbacks of climate change. Human activities are also an major factor which is responsible for soil degradation such as deforestation, overgrazing by cattle's, excessive agrochemical use in agriculture, shifting cultivation, topsoil removal and over-extraction of groundwater are some of the major factors responsible for enhancing soil degradation worldwide. Together, these factors affect sustainable agriculture and environmental stability.

Major Types of Physical Soil Degradation

Soil Compaction

Soil compaction is one of the major types of physical degradation caused mainly by using heavy machineries in agriculture, livestock trampling and intensive tillage are the effect caused by compaction which ultimately increases the bulk density, reduces pore space and limits water, air and root movement in the soil. Some other effects like wet soil conditions, repeated machinery passes in the land, low organic matter and use of heavy axle, loads further increases compaction (Hamza and Anderson, 2005). Generally in compaction the soil particles were rearranged by applied stress which causes reduction of pore spaces and volume of the soil.

Surface Sealing and Crusting

Surface sealing majorly causes when soil particles disperse and block pores due to raindrop impact or excess sodium, the major causes of surface sealing can be intense rainfall, irrigation with high-impact water, low organic matter, high silt or fine sand content and destruction of soil aggregates and its effects where it reduces infiltration, run off, erosion, aeration and poor seed emergence. Whereas, soil crusting defined as the hardening of the soil surface due to sealed surface dries. Basically, the formation process for crusting is soil aggregates dispersed through raindrops; then fine particles clog pores and after drying the sealed layers harden into crust. The effects of crusting are difficulty in seedling emergence, reducing infiltration, increasing evaporation, runoff, erosion and improper root growth.

Water-logging

Water-logging is a severe form of soil degradation which occurs in the condition where excess amount of water accumulates in the soil due to poor drainage, heavy rainfall or improper irrigation practices. Water-logging consists of various types such as surface water-logging, subsurface water-logging, seasonal and permanent water-logging. The major causes are heavy rainfall, poor drainage, flooding, deforestation, poor irrigation management, canal seepage which ultimately results in reducing soil aeration, creating anaerobic conditions and improper crop growth and poor nutrient uptake. Some crops which are sensitive to water-logging are cotton, onion, potato, pulses, strawberry and wheat while in some cases if water-logging continues than it may convert productive land into a wasteland (Dagar *et al.*, 2013).

Erosion

Erosion is the most common form of soil degradation in which the soil particles transport from one place to another occurs through water and wind action. Water erosion is defined as the detachment and removal of soil particles by raindrops, runoff or flowing water and it includes splash, sheet, rill and gully erosion types; whereas, wind erosion occurs through processes like suspension, saltation and surface creep which are common in arid and semi-arid regions. These types of water and wind erosion remove fertile topsoil and reduce agricultural productivity.

Subsidence of Organic Soils

Subsidence mostly occurs in peat, marshy, wetlands and organic soils where drainage lowers the water table which further leads to oxidation, shrinkage and compaction of organic matter in the soil. The characteristics of soils are dark in colour, low bulk density, high in porosity, high WHC and spongy in nature which gives rise in land surface lowering, loss of productivity and greenhouse gas emissions.

Desertification

Desertification is a severe type of land degradation in which fertile land gradually loses its productivity, biological potential due to climatic conditions and human activities generally occurs in arid and semi-arid regions. Drought, overgrazing, deforestation and unsustainable cultivation caused by human activities. India has significant desertification problems in states like Rajasthan, Gujarat, Haryana, Punjab and dry Himalayan regions.

Loss of Soil Structure

Form of physical soil degradation in which natural arrangement of soil particles and aggregates is destroyed due to excessive tillage, erosion, compaction and low organic matter which is responsible for poor soil aggregation and reducing soil stability. Loss of soil structure decreases water-holding capacity, aeration and resilience to erosion.

Management Approaches

Management of physical soil degradation involves integrated and sustainable soil management practices. Soil compaction can be reduced through controlled traffic farming, deep tillage practices, addition of organic matter, using proper machinery and crop rotation with cover crops. Surface sealing and crusting can be managed through conservation tillage, organic amendments, addition of gypsum in alkaline soils, contour farming and efficient irrigation approaches. Water-logging can be controlled by using proper drainage systems, regulating irrigation methods and groundwater management techniques. Erosion can be managed through

terracing, vegetation cover, windbreaks, strip cropping and constructing check dams to reduce soil loss by water and wind. Desertification can be managed through afforestation, mulching, moisture conservation and erosion control structures. Organic soil degradation and subsidence can be managed through maintaining higher water tables, limiting groundwater extraction and restoring vegetation cover. Restoration of soil structure depends on long-term management practices such as organic manure application, reducing tillage, crop diversification, soil cover maintenance and balanced chemical use for improving soil health and sustainability.

Conclusion

Physical soil degradation signifies a serious threat to global food safety and environmental sustainability. Dynamic management principles include lowering of soil disturbance through conservation tillage, maintaining continuous soil cover through cover crops and residue management, diversifying cropping systems to enhance soil biological activity and using organic amendments to improve soil structure and fertility.

Soil degradation can be managed through adopting various integrated approaches which combines management strategies, appropriate policy support, farmer education and economic incentives. Long-term monitoring and adaptive management are important for safeguarding the effectiveness of restoration efforts. Future challenges include adapting management practices to climate change impacts, grading up successful interventions across landscapes and developing cost-effective technologies for small-scale farmers. Addressing these challenges requires continued research, innovation and collaboration among scientists, policymakers and land managers. The final goal of soil degradation management is to maintain healthy, productive soils which help in supporting sustainable agricultural systems while providing essential ecosystem services.

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