



Natural Chemical Soil Degradation: Impact on Agriculture and Remedial Strategies

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Soil degradation in India is estimated to be occurring on 147 million hectares (Mha) of land, including 94 Mha from water erosion, 16 Mha from acidification, 14 Mha from flooding, 9 Mha from wind erosion, 6 Mha from salinity, and 7 Mha from a combination of factors. This is extremely serious because India supports 18% of the world's human population and 15% of the world's livestock population, yet has only 2.4% of the world's land area. Despite its low proportional land area, India ranks second worldwide in farm output. Agriculture, forestry, and fisheries account for 17% of the gross domestic product and employ about 50% of the total workforce of the country. Causes of soil degradation are both natural and human-induced. Natural causes include earthquakes, tsunamis, droughts, avalanches, landslides, volcanic eruptions, floods, tornadoes, and wildfires. Human-induced soil degradation results from land clearing and deforestation, inappropriate agricultural practices, improper management of industrial effluents and waste, overgrazing, careless forest management, surface mining, urban sprawl, and commercial/industrial development. Inappropriate agricultural practices include excessive tillage and use of heavy machinery, excessive and unbalanced use of inorganic fertilizers, poor irrigation and water management techniques, pesticide overuse, inadequate crop residue and/or organic carbon inputs, and poor crop cycle planning. Some underlying social causes of soil degradation in India are land shortage, decline in per capita land availability, economic pressure on land, land tenancy, poverty, and population increase. In this review of land degradation in India, we summarize

- (1) The main causes of soil degradation in different agro-climatic regions
- (2) research results documenting both soil degradation and soil health improvement in various agricultural systems
- (3) Potential solutions to improve soil health in different regions using a variety of conservation agricultural approaches.

Sources of Land Degradation

Land degradation is not being adequately addressed, but it is of vital importance to raise awareness so that future land management decisions can lead to more sustainable and resilient agricultural systems. Of India's total geographical area (328.7 Million Hectares), 304.9 million hectares comprise the reporting area, with 264.5 Million Hectares being used for agriculture, forestry, pasture, and other biomass production. The severity and extent of soil degradation in the country have been previously assessed by many agencies (Table 1). According to the National Bureau of Soil Survey and Land Use Planning [1], ~146.8 million hectares (Mha) are degraded. Water erosion is the most serious degradation problem in India, resulting in loss of topsoil and terrain deformation. Based on a first approximation analysis of existing soil loss data, the average soil erosion rate was ~16.4 tons ha⁻¹ year⁻¹, resulting in an annual total soil loss of 5.3 billion tons throughout the country [2]. Nearly 29% of total

eroded soil is permanently lost to the sea, while 61% is simply transferred from one place to another and the remaining 10% is deposited in reservoirs.

Types of Soil Degradation

Soil degradation implies a decline in soil quality with an attendant reduction in ecosystem functions and services. Conceptually, there are four types of soil degradation: (i) physical; (ii) chemical; (iii) biological; and (iv) ecological. Soil physical degradation generally results in a reduction in structural attributes, including pore geometry and continuity, thus aggravating a soil's susceptibility to crusting, compaction, reduced water infiltration, increased surface runoff, wind and water erosion, greater soil temperature fluctuations, and an increased propensity for desertification. Sustainability 2015, 7 5877 Soil chemical degradation is characterized by acidification, salinization, nutrient depletion, reduced cation exchange capacity (CEC), increased Al or Mn toxicities, Ca or Mg deficiencies, leaching of $\text{NO}_3\text{-N}$ or other essential plant nutrients, or contamination by industrial wastes or by-products. Soil biological degradation reflects depletion of the soil organic carbon (SOC) pool, loss in soil biodiversity, a reduction in soil C sink capacity, and increased greenhouse gas (GHG) emissions from soil into the atmosphere. One of the most severe consequences of soil biological degradation is that soil becomes a net source of GHG emissions (i.e., CO_2 and CH_4) rather than a sink. Ecological degradation reflects a combination of the other three, and leads to disruption in ecosystem functions such as elemental cycling, water infiltration and purification, perturbations of the hydrological cycle, and a decline in net biome productivity. The overall decline in soil quality, both by natural and anthropogenic factors, has strong positive feedbacks leading to a decline in ecosystem services and a reduction in nature conservation. Once the process of soil degradation is set in motion, often by land misuse and soil mismanagement along with extractive farming, it feeds on itself in an ever-increasing downward spiral.

- a) Salinization
- b) Calcareousness
- c) Alkalinization
- d) Acidification
- e) Contamination

a. Salinization

Salinization- Salinization is the process of accumulation of free salts such as Na, K, Ca, Mg and Cl^- , SO_4^{2-} to such an extent that it leads to the degradation of soils and hinders the growth of plants by limiting their ability to take up water.

Saline soils have $\text{EC} > 4 \text{ dSm}^{-1}$, $\text{pH values} < 8.5$ and $\text{ESP} < 15$.

Salinization of soil is an **excessive accumulation of water-soluble salts**. Typically, it is table salt NaCl . The list is far more extensive and includes various compounds of sodium, potassium, calcium, magnesium, sulfates, chlorides, carbohydrates, and bicarbonates. In general, salt-affected earths are categorized as saline, sodic and saline-sodic, depending on the content.

Causes of Soil Salinization

Soil salinization occurs when soluble salts are retained in the earth. It happens either naturally or because of improper anthropogenic activities, particularly farming practices. Besides, some earths are initially saline due to low salt dissolution and removal. Soil salinization causes include:

- Dry climates and low precipitation when excessive salts are not flushed from the earth
- High evaporation rate, which adds salts to the ground surface
- Poor drainage or waterlogging when salts are not washed due to a lack of water transportation;
- Irrigation with salt-rich water, which amplifies salt content in the earths
- Removal of deep-rooted vegetation and a raised water table as a consequence;
- Leakage from geological deposits and penetration into groundwater

- Sea-level rise when sea salts seep into lower lands

Surface Changes Because Of Salinization

- Damp areas and waterlogging
- Ground whitening at early stages and salt crystals at late ones
- Increased water level in furrows
- Bare soils (where plants fail to grow due to salinization)
- Deterioration of roads, buildings, etc.
- White or dark circles around water bodies.

Soil Salinity Control and Prevention

Soil salinization prevention bases on avoiding excessive salt penetration. Even though plants require a certain number of salts to develop, their needs are small compared to the content in salt-affected soils. Here are some **typical methods to prevent soil salinization**:

- Optimize irrigation (reduce salty water usage, implement [drip irrigation](#), use desalinated, recycled, rain-harvested water, and don't overirrigate).
- Add organic matter and manure to keep moisture and reduce irrigation.
- Restrain from deep tillage/heavy machinery not to transfer soil salts to the root zone area, which induces salinization.
- Use **cover** crops or mulch to protect the ground surface.

b. Calcareousness

Accumulation of high amounts of carbonates of calcium and magnesium in soil are called calcareousness and soil development resulting this are calcareous soil. Calcareous soils are widely spread in arid and semiarid regions. It has been estimated that these soils comprise over one-third of the world's land surface area. In Egypt, the calcareous soils constitute about 25-30% of the total area according to the Ministry of Agriculture's estimation. The highly calcareous soils in the North Western Coastal zone (about 3 million acres) offer great possibilities for land reclamation and development to help in solving the shortage of food production, taking into consideration the available rainfall in that area.

Calcareous soils are identified by the presence of calcium carbonate (CaCO_3) in the parent material and an accumulation of lime. This is most easily recognized by the effervescence (fizzing) that occurs when these soils are treated with dilute acid. The pH of these soils is usually above 7 and may be as high as 8.5. When these soils contain sodium carbonate, the pH may exceed 9. In some soils, CaCO_3 can concentrate into very hard layers, termed caliche, that are impermeable to water and plant roots. When P fertilizer is added to calcareous soils, a series of fixation reactions occur that gradually decrease its solubility and eventually its availability to plants.

Characteristics of Calcareous Soils

- Usually have alkaline soil reaction ($\text{pH} > 7.0$) and High buffering capacity.
- Soils are dominated by carbonates of calcium and magnesium; mainly, soils contain CaCO_3 in free form. CaCO_3 may occur in different forms (powder/nodules) with reduced availability of N, P, K, S, Fe, Zn, and B.
- Iron deficiency due to high CaCO_3 leads to chlorosis, also called lime-induced iron chlorosis and reduced rate of seed germination.
- Decreased water holding capacity (WHC) due to alteration in soil structure, formation of hard pan.
- Flocculation due to enough Ca and Mg present in calcareous soil increases aggregate stability and when a large percentage ($> 30\%$) of CaCO_3 is present in the clay fraction, the soils WHC can be reduced.

c. Alkalinization

- ❑ Accumulation of a high amount of exchangeable sodium on soil colloidal complex are called alkalinization
- ❑ Soil developed by these processes are called alkali soil.
- ❑ Alkali soil have $\text{pH} > 8.5$, $\text{ESP} > 15$, EC_e is $< 4 \text{ dSm}^{-1}$ and $\text{SAR} > 13$.

Natural Source of Alkalinization in Soil

- ❑ Parent materials from alkali rocks
 - Abundant sodium aluminosilicates such as orthoclase, plagioclase, albite, sodalite, nepheline (Lin *et al.*, 2005)
- ❑ Geomorphic patterns
 - Neotectonic movement
 - Move downward with the runoffs
- ❑ Climatic conditions
 - Monsoon climate
 - Annual evaporation
- ❑ Effect of freeze-thaw action on soil alkalization
 - Capillary action
 - Thickening of freezing layers
 - Salt conveyed by wind
- ❑ Water environment on soil alkalization
 - Rivers and runoffs
 - Groundwater

The causes of soil alkalinity can be natural or man-made

- ❑ The natural cause is the presence of soil minerals producing sodium carbonate (Na_2CO_3) and sodium bicarbonate (NaHCO_3) upon weathering.
- ❑ Coal-fired boilers/power plants, when using coal or lignite rich in limestone, produce ash containing calcium oxide.
- ❑ Many sodium salts are used in industrial and domestic applications, such as sodium carbonate, sodium bicarbonate (baking soda), sodium sulphate, sodium hydroxide (caustic soda), sodium hypochlorite (bleaching powder), etc. in huge quantities.
- ❑ Another source of manmade sodium salts addition to the agricultural fields/land mass is in the vicinity of the wet cooling towers using seawater to dissipate waste heat generated in various industries located near the sea coast.
- ❑ The man-made cause is the application of softened water in irrigation (surface or ground water) containing a relatively high proportion of sodium bicarbonates and less calcium and magnesium.

• Soil improvement

Alkaline soils with solid CaCO_3 can be reclaimed with grass cultures, organic compost, waste hair/feathers, organic garbage, waste paper, rejected lemons/oranges, etc., ensuring the incorporation of much acidifying material (inorganic or organic material) into the soil, and enhancing dissolved Ca in the field water by releasing CO_2 gas. Deep ploughing and incorporating the calcareous subsoil into the topsoil also helps.

• Leaching saline sodic soils

Saline soils are mostly also sodic (the predominant salt is sodium chloride), but they do not have a very high pH nor a poor infiltration rate. Upon leaching they are usually not converted into a (sodic) alkali soil as the Na^+ ions are easily removed. Therefore, saline (sodic) soils mostly do not need gypsum applications for their reclamation.

d. Acidification

Soil acidity may be defined as the soil system's proton (H^+ ions) donating capacity during its transition from a given state to a reference state. A resulting soil pH decreases below 7.0 is known as acidification

❑ Acidification occurs in agricultural soils as a result of the:

- removal of plant and animal products
- leaching of excess nitrate
- addition of some nitrogen-based fertilisers

build-up in mostly plant-based organic matter

❑ Lime application for permanent pasture

- In permanent pasture situations, spreading the lime on the surface and allowing it to work its way into the soil is acceptable. Surface application is better than no application.
- Lime responses are generally seen in the first and second year for cropping systems, but can take up to 5 years depending on soil type, rainfall and lime quality for permanent pasture systems.

e. Contamination

- Geogenic Arsenic; weathering of the Himalayas leads to the development of aquifers in sands settled on Pleistocene sediments
- Sand aquifers are separated from overlying silts rich in organic matter by a palaeosol rich in clay.
- Arsenic-contaminated groundwater intersects boreholes containing gray sands, which have undergone reductive dissolution.
- Cadmium, a rare but naturally in the environment
- Most cadmium ore (greenockite): exists as cadmium sulfide, is refined during zinc production, and occurs in association with zinc.

Remediation Strategies

➤ Reclamation of Saline Soil

Reclamation of soil can be accomplished by using various strategies. For the successful implementation of each method, a major point of consideration is to provide an adequate soil drainage system (Qadir et al. 2000). However, the suitability of each method depends on many factors:

1. Kinds and concentrations of salts present
2. Availability of good-quality water (low electrolyte concentration) for leaching
3. Texture of subsoil
4. The level of groundwater and its quality
5. Volume of soil that should be reclaimed
6. The landscape of the salt-affected areas
7. The type of plant(s) to be cultivated after reclamation
8. The climatic conditions
9. Availability of time for reclamation
10. Cost-effectiveness (Qadir et al. 2000; Mahanta et al. 2015)

Reclamation of Sodic Soil

Alkali soils, characterized by high pH, excess sodium, and poor soil structure, pose significant challenges to agriculture in India. This paper discusses various remedial strategies, including chemical, biological, and agronomic approaches, to reclaim alkali soils and improve productivity

Alkali soils, also known as sodic soils, affect vast agricultural lands in India, reducing soil fertility and crop yield. Addressing this issue requires integrated soil management techniques.

1. Chemical Amendments

- Gypsum Application: Gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) is widely used to replace sodium ions with calcium, thereby improving soil structure and permeability.
- Sulfur and Sulfuric Acid: These amendments help lower soil pH and enhance nutrient availability.
- Organic Acids: Application of organic acids, such as citric acid and phosphoric acid, can aid in sodium leaching.

2. Biological Approaches

- Green Manuring: Incorporation of green manure crops like Dhaincha (*Sesbania aculeata*) improves organic matter and microbial activity.
- Use of Salt-Tolerant Microbes: Biofertilizers such as *Azospirillum* and *Pseudomonas* enhance soil health and plant growth in alkali conditions.

- Agroforestry Systems: Growing salt-tolerant tree species like *Prosopis juliflora* and *Acacia nilotica* helps in phytoremediation.

3. Agronomic Practices

- Leaching with Good Quality Water: Adequate irrigation with low-sodium water helps wash away excess salts.
- Crop Selection and Rotation: Salt-tolerant crops like barley, sorghum, and cotton can be grown to sustain productivity.
- Mulching and Cover Crops: These practices reduce evaporation and prevent salt accumulation.

4. Policy and Extension Support

- Government Initiatives: Schemes like the Soil Health Card and Rashtriya Krishi Vikas Yojana (RKVY) promote soil health improvement.
- Farmer Training and Awareness: Educating farmers on soil management practices enhances adoption and effectiveness.

➤ Reclamation of calcareous Soil

Nutrient constraints in calcareous soil:

Due to high pH and CaCO₃ content of calcareous soil, most of the soil nutrients such as N, P, K, S, Zn, Fe, Cu, Mn and B very often remain less available to plants (FAO, 2020; Pasricha et al., 2000; Taalab et al., 2019). Generally, in alkaline soils (pH>7), N is lost from soil by the ammonia volatilization process, which is further exacerbated in the presence of CaCO₃ in calcareous soil. The native and considerable amount of applied P in calcareous soil remains adsorbed on clay minerals and CaCO₃ surfaces, and precipitates as calcium phosphates. Thus, P availability to plants in this type of soil is a major problem. Available K and Mg are usually found in adequate amounts; however, in some cases, due to an imbalance of Ca, Mg and K ratios, deficiency of K and Mg appears in plants. In light-textured calcareous soil, leaching loss of SO₄-S occurs. Due to the high pH of calcareous soil, lower solubility of micronutrients like Zn, Fe, Cu and Mn occurs, which results in their deficiencies in plants. However, the deficiency of B in this soil is due to its adsorption on the CaCO₃ surface.

➤ Reclamation of Acidic Soil:

Soil acidity can be corrected easily by liming the soil or adding basic materials to neutralize the acid present. The most commonly used liming material is agricultural limestone, the most economical and relatively easy-to-manage source. The limestone is not very water-soluble, making it easy to handle. Lime or calcium carbonate's reaction with an acidic soil is described below, which shows acidity (H) on the surface of the soil particles. As lime dissolves in the soil, calcium (Ca) moves to the surface of soil particles, replacing the acidity. The acidity reacts with the carbonate to form carbon dioxide (CO₂) and water (H₂O). The result is a less acidic soil (has a higher pH).

• Effects of lime on soil

If a soil is limed to a more suitable pH, the following chemical changes are likely to occur

- The concentration of hydrogen ions will decrease.
- The concentration of hydroxyl ions will decrease.
- The solubility of iron, aluminium and manganese will decline.
- The availability of phosphates and molybdates will increase.
- The percent base saturation will increase with the increased availability of exchangeable calcium and magnesium.
- The availability of potassium may increase or decrease depending on conditions.

Conclusion

The impact of natural chemical soil degradation on agriculture is profound, leading to reduced soil fertility, lower crop yields, and long-term sustainability challenges. Addressing this issue requires an integrated approach that combines chemical amendments, biological interventions, and agronomic practices. Strategies such as gypsum application, green manuring, and crop rotation play a vital role in restoring soil health. Additionally, policy

support and farmer education are essential for the widespread adoption of these practices. By implementing effective remedial measures, agricultural productivity can be sustained, ensuring food security and environmental stability for future generations.

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