IIP International Multidisciplinary Research Journal
IIPIMRJ

An Online Peer-Reviewed / Refereed Journal
Vol: 02 No. Issue IV, (October-December) (2025)
Impact Factor: GSRD-IF: 5.001
ISSN: 3049-2734 (Online)

Impact of Soil Degradation on Agricultural Transformation and Food Security: Challenges and Sustainable Solutions

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Article Info

Article History:

Received: 15th Dec 2025

Accepted: 19th Dec 2025

Published: 20th Dec 2025

Keywords:

Soil degradation,
Agriculture,
Food security

ABSTRACT

Soil degradation, which has been described as a very significant environmental topic, has been classified among the most critical factors that endanger agricultural productivity and food security in all parts of the world. Soil degradation, however, this is the process of natural and human activities whereby the soil loses its physical, chemical and biological properties. The repercussions soil degradation, in particular, are the disappearance of nutrients, soil slipping away, salt content being raised, and pollution, which all combine to give lower crop yields, poorer quality food and slower agricultural transformation as a result. Soils are not only indispensable elementary components of the earth's surface but their degradation affects human populations as well in the long run. The paper gives a thorough and thoughtful account of soil degradation, its classification, causation and impacts on agriculture and food security, besides the corresponding sustainable management techniques. Integrated soil management, conservation agriculture, organic amendments and policy interventions have been scientifically proven to be, not only the key factors in the prevention of soil degradation but also the ones extending soil fertility and the duration of food security in the future.

Plagiarism Check Report:

Tool Used: Turnitin

Date of Report: Dec 18, 2025

Similarity Index: 9%

Remarks: No significant matching text. All citations and matches are properly referenced. The manuscript is considered original.

How to Cite: Madavi, A. B., & Mane-Deshmukh. (2025). Impact of soil degradation on agricultural transformation and food security: Challenges and sustainable solutions. IIP: International Multidisciplinary Research Journal (IIPIMRJ), 2(IV), pp. 1038–1046.

1. INTRODUCTION

Soil has always been and still is the primary resource that differentiates the different land ecosystems on earth (Buée *et al*., 2009). Its richness also makes it the arena of interaction among the three groups of organism's plants, microbes, and animals. In this sense, the soil's foremost function is to sustain life, then as in the case of humans it gives support; thus, it is the home of millions of organisms and the whole cycle of biodiversity and ecosystems' balance is thus continuously refreshed, non-stop (Stewart *et al*., 2021). In addition, soil is also the great restoring power of nature; it is the very base of agriculture and still, the continent's agricultural operations are dependent on soil for its existence. Good soil is where the plants prosper because they get their vital nutrients: nitrogen, phosphorus, and potassium. Another reason for soil fertility is the presence of decayed plants and animals in the soil for a long period (Javed *et al*., 2022; Osman *et al*., 2012). Soil has been the path through which terrestrial life and humanity have experienced tremendous trials. Moisture control is one of the most important functions that soil carries out. The water control that takes place because of the soil's efficient natural reservoir is the main way; it captures rainwater, keeps the soil moist, and slowly gives it to the plants and the underground water systems. Thus, the water cycle that prevents floods, encourages growth in the soil areas, and supplies irrigation for the crops in the dry regions is actively working along with the soil (Bhattacharya, 2021; Kaur *et al*., 2020). Not only that, but soil also blocks impurities from getting into the water and works as a filter thereby supplying clean water for agricultural and human use. In controlling the water cycle, soil contributes to climate stabilization and the mitigation of problems faced by communities with changing rainfall patterns (Naskar *et al*., 2025).

Soil is of great importance and is a must in the nutrient recycling cycle of ecosystems. The mineral nutrients that come from the decay of organic matter are practically the ones that are most needed by the plants (Vepraskas *et al*., 2000; Chen, 1996). Among the ways that soils help the chemical fertilizers application to be reduced and thus support sustainable agriculture indirect nutrient cycling is one of the tops. Also, soils are the homes of numerous different kinds of microorganisms, including those that with their interaction increase the plant nutrient uptake, disease control, and soil physical properties. The nutrient balance that the soil provides not only produces crops but also nourishes and keeps the plants alive (Srivastava *et al*., 2023; Krishna, 2013). The rising human population will have to rely on the fertile soil layers since they are the most critical for the existence of humankind.

On the other hand, soil is still another earth service, besides the carbon sequestration, which is one of the reasons soils helps to mitigate climate change. Soil takes carbon dioxide out of the air and sequesters it as organic carbon and humus. The consequence of this is a decrease in the concentration of greenhouse gases which contributes to the global effort against climate change. Deforestation and cultivation of previously fertile land are the three land use types that can, to a certain degree, alter the soil carbon pool in the atmosphere (Houghton, 1995). The more fertile the soil, the more carbon it will capture and the less it will emit back into the atmosphere, thus soils are the key players in the environmental sustainability equation. Therefore, soil management indirectly does the dual task of increasing farm output and climate moderation.

Moreover, soil is the fundamental element that supports and nurtures human civilization and economy. Agricultural soils that are already processed provide food, fibre and other basic materials for the millions of people living on planet Earth (Revelle, 1976; Lal, 2008). Fertility and productivity of the soil are the main factors of success in farming and, consequently, the end of food security. In addition, the soil supports the infrastructure by serving as a foundation for the construction of buildings, roads, etc. Degraded and less fertile soils bring about the scenarios of famine, economic losses, and a shift in the ecological balance closer (DeLong *et al*., 2015; Rhodes, 2014). Therefore, the protection and restoration of soil health are crucial not only for sustainable development but also for the environment's long-term well-being.

Soil degradation is one of the environmental problems that most affect the availability of land suitable for agriculture and eco-friendly practices (Ononogbo *et al*., 2024). It is a downward movement of soil quality through different physical, chemical, and biological activities, which consist of reducing soil fertility, destructing soil structure, and lowering the water retention capacity of soil to a level that it becomes less suitable for cultivation. Among the agents of soil degradation are erosion, depletion of nutrients, salinization, and pollution (Hossini *et al*., 2022).

The environment suffers from soil degradation and natural processes get unbalanced whereby plants and animals are affected and finally the extinction of species occurs, consequently, it creates a challenge to food supply and land use that is environmentally friendly (Ali, 2024).

physical degradation of soil is mainly caused by water and wind, which leads to the breaking up of soil structure in this whole process takes away the fertile, good soil on the surface, and reduces the soil's ability to hold water besides making the land less productive. The gradual process of erosion can eventually change the land into a desert. Hence, soil health along with agricultural output is very much dependent on erosion control measures.

Chemical degradation is defined as a process where soil nutrients are either completely lost or present in an unbalanced way, and this is usually accompanied by such phenomena as acidification, salinization, and contamination (Saljnikov *et al*., 2021). It has a negative impact on soil fertility, which in turn makes it harder for plants to grow. The major contributors to this process are the extensive use of chemicals and poor irrigation practices. One of the soil chemistry restorers is liming, along with organic amendments, other corrective measures that can be used are also available.

Biological Degradation the process of biological degradation is an indicator of the diminishing of soil diversity and organic matter and it is a complex procedure that eventually leads to, among other factors, the decline of microorganism activities, nutrient cycling, and soil structures' stability (Obalum *et al*., 2017; Zhan, 2024). The whole situation of soil biota depletion is to the plants and ecosystems getting more and more vulnerable. Nonetheless, the biological degradation process can be undone by performing called-for soil-restoring practices like composting and planting cover crops.

Agricultural transformation is one of the most frequently used keywords that describe the complete agricultural sector modernization through the adoption of technology, new plant varieties, and increased output not only between but also across sectors. A good soil foundation is the first principle of modern farming. Soil deterioration results in production decline, which makes both manual and mechanical farming unproductive, so soil management will be the cornerstone of the whole agricultural transformation process (Naskar *et al*., 2025; Mesele *et al*., 2025).

Food security is the condition that can be characterized as a situation where every person has continuous access to safe and nutritious food, while the availability, accessibility, and utilization factors are considered (García-Díez *et al*., 2021). Soil degradation means less food production and consequently food shortages and higher prices. It also exposes the affected people to hunger and malnutrition, making them more likely to suffer from these conditions. In this way, soil protection becomes not only the first condition for acquiring a reliable food system but also for its longevity.

2. METHODS AND MATERIAL:

This review relies on a comprehensive literature survey and secondary data analysis:

DATA SOURCES:

To conduct the review, it was required to pull resources from various disciplines and the most trustworthy ones being the peer-reviewed journals, academic books, conference proceedings, and research done by both government and non-government organizations. Moreover, the FAO and UN databases were the sources from where the topmost global data was obtained. Not only did these sources reach the totality of soil degradation and agricultural impacts, but also enabled very sharp and detailed analyses through the combination of different sources.

SEARCH KEYWORDS:

The found studies that were meaningful to the topic through the help of the keywords "soil degradation," "soil fertility decline," and "agricultural transformation." Apart from these, "food security," "conservation agriculture," and "sustainable soil management" were also regarded as keywords. The selected keywords not only brought forth the environmental and agricultural problems but also the search method was planned in such a way that it would finally allow publications revealing both global and local viewpoints to be obtained.

INCLUSION CRITERIA:

The publications covering the period from 2000 to 2025 only were included in the selection so that data would not be only recent but also relevant. The publications selected for the review dealt with soil degradation impact on crop yield, agricultural practices, and food security. Both primary and review articles were considered in order to reach a thorough understanding. This approach has significantly facilitated the identification of trends, causes, and measures to mitigate the effects.

DATA ANALYSIS:

The study findings were merged to identify the factors and barriers to soil degradation. Among the aspects analysed were the impacts on agriculture regarding crop yield, quality, and degree of mechanization. Food security effects that have to do with availability, access, and stability were also included in the analysis. Lastly, it was decided to evaluate the different courses of action to support and implement sustainable practices in order to derive the most effective solutions.

3. OBSERVATION

Table:1

Type of Soil Degradation	Primary Causes	Impact on Agriculture	Impact on Food Security	Sustainable Management Strategies
Soil erosion	Rainfall, wind, deforestation, overgrazing	Loss of fertile topsoil, reduced yields, uneven growth	Decline in staple crop production, food shortages	Contour farming, cover crops, terraces, afforestation
Nutrient depletion	Monocropping, over-fertilization, crop residue removal	Stunted growth, lower yields, poor quality	Lower productivity affects food supply and prices	Crop rotation, green manure, organic fertilizers, micronutrient supplementation
Salinization	Irrigation with poor-quality water, poor drainage	Poor plant growth, reduced yields	Limited production of cereals and vegetables	Proper drainage, salt-tolerant crops, leaching of salts
Soil contamination	Pesticides, heavy metals, industrial waste	Toxic crop accumulation, reduced productivity	Unsafe food, reduced marketability, health risks	Bioremediation, reduced chemical usage, phytoremediation
Acidification	Excessive chemical fertilizers, acid rain	Nutrient imbalance, poor microbial activity	Loss of crop productivity, instability in supply	Liming, organic amendments, pH monitoring

Loss of organic matter	Intensive tillage, residue burning	Poor soil structure, lower water retention	Reduced resilience of crops, increased vulnerability to drought	Conservation tillage, compost application, crop residue retention

4. **RESULTS :**

Soil degradation adversely affects crop yields by reducing the availability of essential nutrients required for plant growth. It deteriorates soil structure, limiting water infiltration and root penetration, ultimately lowering agricultural productivity. Degraded soils often produce crops of inferior quality, affecting both nutritional value and marketability. As soil fertility declines, farmers face increasing difficulties in maintaining consistent yields across seasons. Long-term productivity drops, making agricultural systems more vulnerable to environmental stresses.

Nutrient depletion is one of the most widespread forms of soil degradation affecting global farmlands. Continuous cultivation without adequate nutrient replacement accelerates the exhaustion of vital macronutrients. Erosion, caused by water and wind, removes the fertile topsoil layer that contains organic matter and minerals. Staple crops such as wheat, rice, and maize show significant yield reductions when grown on eroded soils. These combined processes threaten the sustainability of agricultural landscapes worldwide.

Food security becomes increasingly compromised as soil quality declines over time. Lower crop yields reduce the overall availability of food at local, national, and global scales. Reduced supply often leads to increased price volatility, especially for essential commodities. Communities become more vulnerable to hunger, malnutrition, and the impacts of climate change.

Regions already facing water scarcity or extreme weather conditions are disproportionately affected.

Implementing sustainable soil management techniques can reverse many negative effects of degradation. Practices such as conservation tillage, crop rotation, and organic fertilization enhance soil health.

Improved soil structure increases water retention, supporting crops during dry periods. Sustainable methods also boost microbial activity, which strengthens nutrient cycling. Adopting these practices helps stabilize food production and promotes long-term resilience.

Countries that integrated conservation agriculture into their farming systems observed measurable benefits. Use of organic amendments such as compost and green manure improved soil organic carbon levels. These interventions enhanced plant growth, resulting in yield improvements of 10–25% on degraded lands. Higher productivity reduced dependence on chemical fertilizers, lowering production costs. Such success stories demonstrate the importance of sustainable soil management in securing food systems.

5. DISCUSSION:

Impact on Agricultural Transformation:

Degraded soils reduce the efficiency of modern farming techniques and limit the benefits of mechanization (Misra and Ghosh, 2024), high-yielding varieties fail to reach their potential when soil fertility and structure are compromised. Farmers experience increased production costs as more inputs are needed to maintain yields (Balmford *et al.,* 2018; Reader *et al*., 2018). Overall, agricultural investment becomes less profitable when soil quality continues to decline.

Impact on Food Security:

Declining soil fertility directly reduces crop productivity, threatening food availability in both rural and urban areas (Kopittke *et al*., 2019). Poor-quality soils produce nutritionally inferior crops, leading to dietary deficiencies and health issues. Lower yields increase food prices, making essential commodities less accessible to vulnerable populations (D'Souza and Jolliffe, 2014). Soil degradation ultimately destabilizes food systems and heightens the risk of hunger and malnutrition.

Regional Variations:

Semi-arid regions experience severe erosion, salinization, and desertification due to limited rainfall and high evaporation. Tropical regions often suffer from nutrient depletion, rapid organic matter loss, and soil acidification (Agegnehu *et al*., 2021). Different climatic zones face unique forms of soil degradation based on land use and natural conditions. Regional disparities highlight the need for location-specific soil management and policy strategies (Randolph and Currid-Halkett, 2022).

Soil conservation methods such as terracing, contour ploughing, and a forestation help reduce erosion. Nutrient management through crop rotation, organic amendments, and integrated nutrient management restores fertility (Bayu, 2022). Policy support including subsidies, training programs, and soil monitoring encourages sustainable farming adoption. Effective mitigation requires combining ecological, agronomic, and policy approaches for long-term soil health.

6. FUTURE PROSPECTS:

Precision agriculture, remote sensing, and GIS tools allow early detection and mapping of soil degradation. Technology-driven solutions improve decision-making and optimize resource use at the field level. Integrating traditional farming knowledge with modern innovations strengthens sustainability. Future agricultural resilience depends on proactive soil management and technological advancement.

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