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Impacts of soil degradation on the severity of soil-borne diseases and sustainable management strategies: A review

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Abstract

Land degradation is a significant environmental challenge that impacts over 1.5 billion people globally. Recent assessments indicate that approximately 23% of the Earth's surface is degraded, with alarming projections suggesting this could increase by up to 50% by 2050. Regions particularly vulnerable to severe degradation include Sub-Saharan Africa and South Asia, largely due to socio-economic and climatic changes. Soil degradation is classified into three main forms: physical, chemical, and biological. These forms often interact and influence one another in various ways. Notably, biological degradation is frequently overlooked, despite the critical role of soil biology in maintaining healthy ecosystems. Soil microorganisms are essential for facilitating vital nutrient cycles, including nitrogen, carbon, sulfur, and water, and they also play a crucial antagonistic role against soil-borne plant pathogens. The virulence, growth, motility, and survival of these pathogens are significantly affected by soil degradation, thereby impacting the prevalence and severity of soil-borne diseases. This paper provides insights into soil degradation, focusing mainly on biological degradation and the processes and human activities that contribute to it. It discusses the impacts of biological degradation and other forms on soil-borne diseases and explores their interactions, while also outlining specific management strategies for sustainable soil health improvement.

Keywords: Salinisation, Soil biodiversity, Soil moisture, Soil organic matter, Soil temperature, Soil-borne plant pathogens.

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Contribution of this paper to the literature
This study contributes to the existing literature on the sustainable management of degraded soils. The paper's primary contribution is finding that several approaches can be adopted by farmers to prevent and manage soil-borne plant diseases. This study documents the importance of sustainable management strategies to improve soil health.

1. Introduction

Soil degradation refers to the decreased ability of the soil to produce crops as a consequence of soil erosion and changes to the chemical, biological, physical, and hydrological soil characteristics. It decreases the capacity of land to yield a certain benefit when it is used for a given purpose and managed in a particular way [1, 2]. Land degradation is also defined as the decline of all resources linked to agricultural production, such as landforms, soil, vegetation, water resources, and climate [3, 4]. Land degradation is mainly caused by human activities such as over-cultivation, deforestation, mining, and construction, or by natural phenomena like wind, earthquakes, and volcanic eruptions [5-7]. Three broad categories of land degradation exist: natural, human-induced, and desertification [4]. The most severe type of land deterioration, known as desertification, affects 40% of the earth's surface in dryland areas.

The most recent UN Global Land Outlook study states that over 40% of the planet's land area is degraded (Figure 1), with 965 million hectares worldwide affected by human-induced degradation [8]. Human-induced land degradation predominantly impacts countries in Africa and Asia (Table 1). This is mainly due to climate change and socio-economic constraints. In Africa, these countries include Ghana, Congo, Equatorial Guinea, Angola, and Zambia; in Asia, reports have indicated that countries like Malaysia, Bhutan, the Republic of Korea, Thailand, and Laos are affected [9]. Approximately 55% of the world's drylands are found in Asia and Africa. Furthermore, Prăvălie [5] reports that Pakistan and Afghanistan are at risk of desertification. According to Lal [10], biodiversity, agricultural productivity, and ecosystems are all seriously threatened by land degradation. Land degradation is associated with on-site and off-site adverse effects. Crop and animal output declines are evidence of off-site impacts, while siltation of riverbeds and reservoirs, reduced water quality, and sand deposition from wind erosion are examples of on-site effects [3, 11].

The rate at which soil degradation occurs varies and is determined by anthropogenic factors such as cropping systems, management techniques, and soil features, including vegetation and climate. There are several kinds of soil deterioration, each with unique characteristics and effects [12-14]. Soil erosion is an example of a process that lowers the fertility and structure of the soil. It occurs when water or wind eliminates the topsoil layer [15]. According to Curtis et al. [16], deforestation, or the removal of forests for urbanization or agriculture, results in interference with carbon cycles and biodiversity loss. Another form is salinization, which is caused by soluble salt accumulation in the soil that makes it unfit for growing crops [17]. Loss of organic matter, lowered soil fertility, salinization, increased buildup of heavy and toxic metals, and soil loss are all signs of degraded soil [4].

Soil degradation is classified into three forms: physical, chemical and biological degradation (Table 2). In comparison to other forms of soil degradation, biological degradation is often overlooked despite its potential contribution to soil health and productivity [18-20]. Biological soil degradation is an important aspect because it is responsible for the nitrogen, carbon, sulfur, and water cycles that are facilitated by soil microbes and faunal composition through the interaction with chemical and physical properties [21, 22]. Biological soil degradation encompasses some processes that negatively affect the soil fauna or flora in the soil [19].

Table 1. Types of soil degradation.

Type	Example of a process	Reference (s)
Physical	Soil erosion by wind and water, soil compaction, waterlogging, sealing and urbanization, crusting, and desertification.	Osman [23]; Lal [10], and Dragović and Vulević [24]
Chemical	Salinization, excess leaching, nutrient depletion and accumulation of toxic chemicals, acidification, loss of organic matter and/or nutrients.	Dragović and Vulević [24]; Eswaran et al. [9], and Osman [25]
Biological	Loss of soil biodiversity, reduced soil organic matter.	Lehman, et al. [19] and Mishra and Dhar [26]

2. Methodology

This review employed the Preferred Reporting Items for Systematic Study and Meta-Analysis (PRISMA) technique, which was previously used by researchers [27, 28]. Various databases were utilized as information sources, including Google Scholar, which was the major database used for obtaining initial article samples. Scopus, PubMed, and Worldwide Science were the other sources considered. A variety of broad search terms, including soil degradation, soil-borne pathogens, illness incidence, severity, microbial community, soil amendment, and climate change, were used to build a collection of primarily peer-reviewed research articles. The search spanned the database until 2024 and included journal articles, review articles, and research reports written in English.

The articles were assessed based on two criteria: firstly, their appropriateness and relevance to the purpose of this study; secondly, their credibility as peer-reviewed publications. Articles were considered after reviewing abstracts and findings that included variables based on search titles, as well as appropriate experimental design and statistical analysis. Additionally, information from other relevant journals and sources containing research articles matching the scope of this literature review was also incorporated [29] (Figure 1).

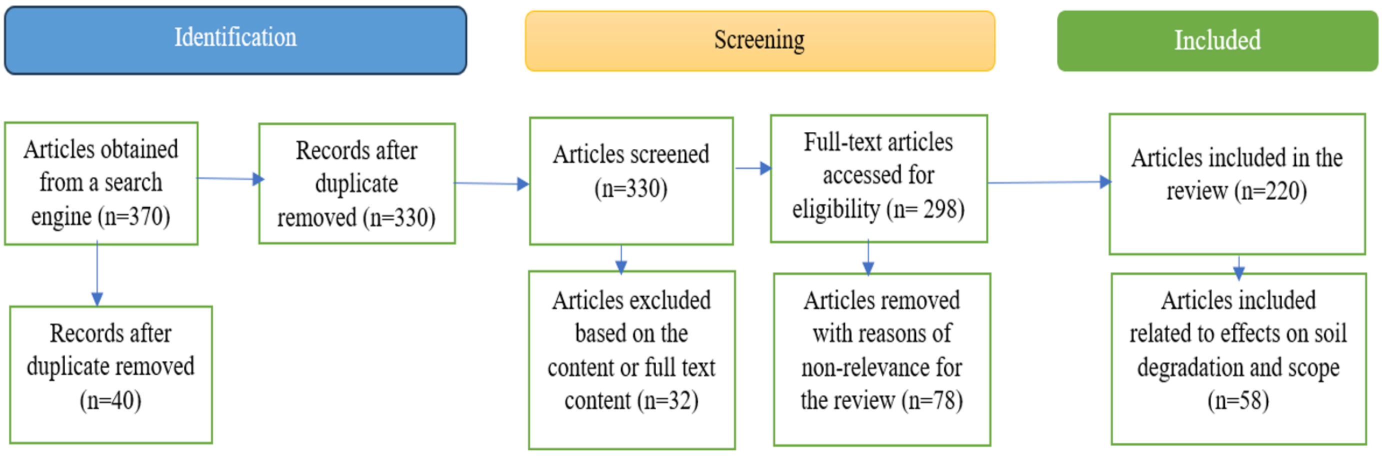

Figure 1. A systematic review based on the PRISMA approach, modified by O'Dea et al. [27].

3. Findings of the Review

3.1. Soil-Borne Plant Diseases

The kind of plant diseases that are induced by pathogens that are soil inhabitants and primarily affect the plant's roots, stems, and other underground parts, eventually can kill the entire plant [30-32]. The yield loss between 50-75% has been reported to be associated with soil-borne plant diseases. Common microbial species responsible for soil-borne plant diseases include *Phytophthora spp*, *Verticillium spp*, *Rhizoctonia spp*, *Pythium spp*, *Fusarium spp*, *Phytophthora spp*, and *Verticillium spp*. They affect major groups of food crops such as maize, wheat, cotton, vegetables, and fruit crops [33-35]. Table 2 shows some examples of plant diseases caused by soil-borne pathogens.

Table 2. Example of soil-borne plant diseases.

Disease	Pathogen	Symptoms	Reference
Fusarium wilt in tomatoes	*Fusarium oxysporum f.sp. lycopersici*	Wilting, yellowing, and browning of leaves, leading to plant death.	Devi, et al. [36]
Rhizoctonia root rot in potatoes	*Rhizoctonia solani*	Reduced emergence, stunted growth, and dark lesions on the stems and tubers.	Heflish [37]
Phytophthora root rot in avocados	*Phytophthora cinnamomi*	Wilting, yellowing, and dieback of the leaves lead to tree decline and death.	Bekker [38]
Clubroot in Brassica crops	*Plasmodiophora brassicae*	Large, club-shaped galls on the roots can disrupt nutrient and water uptake, stunt growth, and reduce yields.	Saharan, et al. [39]

Since many diseases seem to share identical symptoms, it can be difficult to accurately diagnose one from the other. These include, but are not restricted to, twig or branch dieback, bark cracking, wilting, yellowing, root blackening, stunting, seedling damping-off, and root rot [40]. All of these factors make the disease more difficult to control. Long-term survival of these infections is frequently observed in host plant detritus, soil organic matter, free-living organisms, or resistant structures such as chlamydospores, oospores, microsclerotia, or sclerotia [41, 42].

These diseases are regarded as an important factor that limits crop yield. They are primarily caused by fungi, viruses, and bacteria and persist in the soil, often leading to significant agricultural losses and ecological imbalance. Common examples include Fusarium wilt, caused by the Fusarium species, bacterial wilt caused by *Ralstonia solanacearum*, and root rot, linked to *Phytophthora spp* [43]. Soil health is a principal factor that affects the management of soil-borne diseases. Through normal biological processes, healthy soils that are high in organic matter and beneficial microbes can inhibit threatening diseases [44, 45]. But soil becomes more vulnerable when it is weakened by unsuitable management techniques or changes in the environmental conditions [19, 46]. The spread of diseases transmitted by soil is influenced by several factors (Figure 2). The factors can alter the soil environment, making it more conducive to pathogen survival and proliferation [47]. The knowledge of these dynamics is crucial for formulating effective management strategies to mitigate the impact of soil-borne diseases on agriculture and ecosystems.

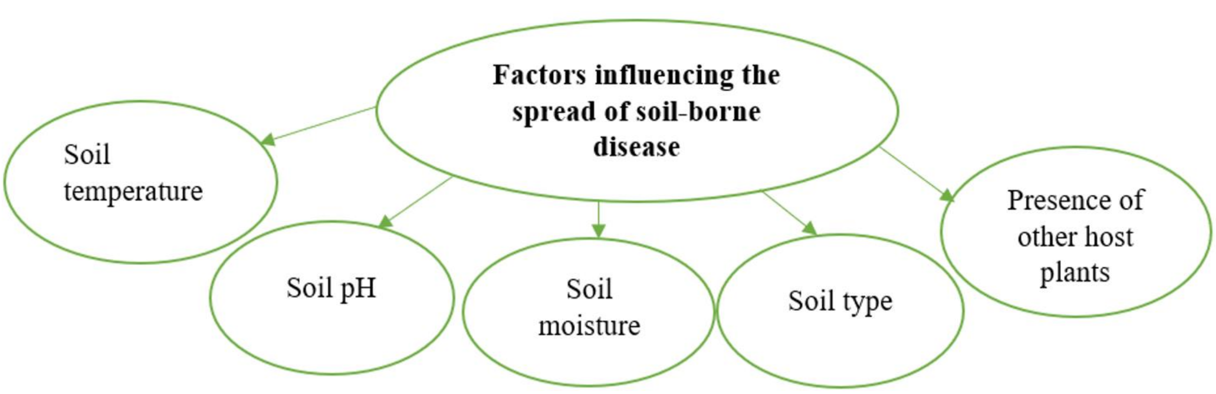

Figure 2. Factors influencing the spread of plant soil-borne diseases.

When biological degradation occurs, it leads to a reduction of soil vegetation cover, decreased vegetation diversity, altered biomass of microbial communities, a change in species and biodiversity composition, loss of soil flora, loss of soil macro and microorganisms and increased pests and diseases [45, 48, 49]. According to Teixeira et al. [50], poor soil structure, low organic matter, low soil fertility, high soil compaction, and insufficient drainage are all contributing factors to the effects of soil degradation. For example, Fusarium root rot development can be triggered by the environmental conditions of the soil.

Furthermore, plant soil-borne pathogens, which form part of the soil fauna, are thought to be affected by soil degradation [51]. Additionally, Patel et al. [52] indicated that when soil conditions are not favorable, soil-borne pathogens become more damaging. Examples of plant-borne pathogens that have been reported to be impacted by soil degradation include Rhizoctonia solani, whose build-up increases in reduced tillage fields, with unmulched fields having lower pathogen populations and severity of the disease.

4. Effects of Soil Degradation on Soil-Borne Plant Diseases

4.1. Salinization

Soils that exhibit an electrical conductivity of greater than 4 dS m−1 or less than 40 mM NaCl at 25 °C for the saturation extract are classified as saline. According to estimates, about 20% of land suitable for agriculture is affected by salinity, and it is projected that by 2050, that percentage could reach up to 50% [53]. Several physiological processes (such as respiration, photosynthesis, DNA replication, nutrient and water absorption, respiration, and protein metabolism) are inhibited by high salinity in salt-sensitive plant species and certain salt-tolerant or halophyte species (Table 3) [54, 55]. High salinity inhibits many physiological processes in salt-sensitive plant species as well as some halophytes or salt-tolerant species, including respiration, photosynthesis, DNA replication, water and nutrient absorption, and protein metabolism [54-56].

In highly saline soils, plants are more vulnerable to infection by soil-borne diseases, according to several studies [42, 57, 58]. Certain soil-borne diseases have been found to develop more readily in soil with higher salinities. For instance, a study by Hellman et al. [59] examined by measuring inoculum density, the development of Fusarium oxysporum f. sp. lycopersici was positively influenced by increased salts from irrigation water and soil. Furthermore, salinity stress makes plants more vulnerable to a range of pathogens, which exacerbates plant diseases by raising the prevalence of disease.

Table 3. Effects of salinization on plants.

Effect	Reference (s)
Water and nutrient absorption	Hussain, et al. [54] and Otlewska, et al. [55]
DNA replication	Otlewska, et al. [55] and Mazhar, et al. [56]
Reduced photosynthetic rate	Otlewska, et al. [55] and Hussain, et al. [54]
Inhibition of respiration	Jacoby, et al. [57]
Inhibition of protein metabolism	Bandehagh and Taylor [58]

Under extremely hot conditions, higher salinity affects several processes associated with pathogen growth and development. These include chlamydospore generation, pathogen sporulation in plant vessels, and general fungal development [60]. In Africa, Ethiopia is reported to have the largest salt-affected landmass (11 hectares), making it the seventh in the world (Figure 3).

Figure 3. Part of the highly salt-affected area in Ethiopia.
Source: Qureshi, et al. [61].

According to the findings of an experiment by Haller et al. [62], which examined the impact of elevated salts on the immune system of Arabidopsis thaliana, plants became more susceptible to necrotrophic Botrytis cinerea, necrotrophic Alternaria brassicicola, and hemibiotrophic Pseudomonas syringae when the ordinary responses to salt stress are triggered by acting as a regulatory function. The hormonal imbalance resulting from higher salt levels was the cause of enhanced vulnerability of A. thaliana [63].

The effect on morpho-physiological and yield attributes resulting from increased severity of Fusarium wilt was recorded from a greenhouse study to assess the combined effect of salinity and Fusarium oxysporum f.sp. cepa. The effects recorded included a decline in the membrane stability index, total protein content of the leaf, general osmotic potential, and total chlorophyll in onion plants [64-66]. In another in-vitro and pot experiment by Tiwari et al. [67], it was revealed that a significant increase in Fusarium wilt disease severity was caused by the rise in salt concentration. But also, Mansha et al. [64] reported that salinity is an important factor that contributes to increased incidence severity for soil-borne diseases.

4.2. Moisture Availability

Soil degradation results in changes in the moisture levels, and it can be aggravated by floods and the desertification process [2]. Soil moisture plays a potential role in the development of soil-borne pathogens. A study by Narisawa et al. [68] revealed that disease occurrence significantly increases with the rise in the soil moisture level. For example, the disease occurrence at a 40% moisture level is independent of the spore density. An increase in soil moisture significantly increases the level of pathogen colonization in the seedlings, as high moisture promotes spore germination, dispersal and infection [49]. The strong correlation between the increase in humidity and the severity of soil-borne plant diseases was confirmed in a study involving Pseudomonas syringae and M. oryzae pathogens in the plant phyllosphere.

The soil moisture level affects soil-borne pathogens in several ways such as pathogen survival and growth in the soil [68-70]. Other pathogenic soil-borne microbe groupings, like R. solanacearum, have also shown a correlation between moisture levels and the severity of soil-borne diseases [70, 71]. Moisture has been used as the most significant factor in predicting disease occurrence across various regions. Oomycetes and root-infecting fungi are reported as the major groups of plant pathogenic fungi present at various soil moisture levels [72]. High moisture level in the soil facilitates pathogenic plant zoospores' movement to the plant roots [73].

According to Berendsen et al. [74], during high pathogen abundance, the plant response is determined by the ability of the plant to survive stress conditions and the kind of microbes colonizing the roots. However, some species of microbes found in the rhizosphere play a potential role in improving the resistance of plants to pathogens. Also, the amount and composition of the rhizosphere microbiome influence pathogenic microorganisms to colonize the plant roots [71, 75]. Table 4 shows soil-borne disease severity as influenced by the level of moisture conditions in the soil.

Table 4. Severity of soil-borne diseases as influenced by different soil moisture conditions.

Pathogen	Host	Soil moisture condition	Severity of the diseases	Reference
Fusarium spp.	Cereals	Dry soil	More severe	Hollaway, et al. [76] and Saad, et al. [77]
Streptomyces scabies	Potato	Dry soil	More severe	Nisa, et al. [78] and Mushinskiy, et al. [79]
Macrophomina phaseoli	Sorghum	Low soil moisture	Most severe	Pandey and Basandrai [80]
Gaeumannomyces graminis	Cereals	Low moisture	Most severe	Saad, et al. [81] and Aranda, et al. [82]

4.3. Soil Organic Matter

Soil erosion is one of the main causes of the loss of soil organic matter [83]. In comparison to other kinds of organic matter like crop residue, compost can inhibit soil-borne illnesses by 50%, according to a laboratory-scale experiment conducted by Neher et al. [84]. They estimated that 15 tonnes per hectare is the ideal rate of compost usage for controlling soil-borne diseases. However, it has been pointed out that several factors, including soil type, pH, texture, and organic matter type, influence how well compost inhibits soil-borne pathogens [85-88].

Santos et al. [89] added that an aggressive soil-borne pathogen (Rhizoctonia solani) infects crops from Solanaceae, Fabaceae, Asteraceae, and Brassicaceae and causes potential yield losses. For instance, R. solani was able to cause up to fifty percent yield loss in lettuce cultivated in the US. R. amending the soil with composts prepared from lignocellulosic substrates, such as tree barks, has been reported as an effective approach to control this pathogen.

The depletion of resources such as organic materials by the indigenous microbial communities has been reported as one of the mechanisms used to suppress the growth and infection induced by soil plant pathogens [17, 90]. For instance, Streptomycetes spp. tend to utilize wild rocket or rice bran debris, which helps to suppress pathogens such as Fusarium oxysporum and potato scab diseases [91-93].

Many soil-borne plant diseases, including Sclerotinia drop (Sclerotinia sclerotiorum) of lettuce, Fusarium wilt (F. oxysporum f. sp. cucumerinum) of cucumbers, and Rhizoctonia root rot (Rhizoctonia solani) on beans and cotton, can be suppressed by adding compost to the growing medium. Compost is essential for the biocontrol of soil-transmitted plant diseases [69, 86].

4.4. Elevated Temperature

The activities of soil microorganisms are highly dependent on soil temperature [94]. This finding aligns with the study by Yan and Nelson Jr [95], which found that a significant reduction in seedling emergence occurred at a soil temperature of 10°C associated with Fusarium solani and F. trincticum, whereas infection was achieved at temperatures between 10°C and 20°C. Soil temperature is negatively correlated with soil moisture; this is confirmed by the results of Yan and Nelson Jr [95], who observed that high incidences of soil-borne diseases are recorded during lower temperatures because low moisture favors the growth and development of soil-borne pathogens. At 18°C and 28°C, the majority of infections were observed at soil moisture levels of 20% to 80% WHC and 40% to 80% WHC, respectively. It was shown that F. solani disease thrived at 18°C with high soil moisture (60% to 80% WHC) or at 28°C with low soil moisture (20% to 40% WHC). In contrast, F. trincticum disease was more likely to occur in colder temperatures and lower soil moisture levels.

It was found that soil temperature had a substantial impact on the severity of Fusarium root rot ($P < 0.05$). From 10 to 20 degrees, there was an increase in the length of lesions and the incidence of diseases caused by F. solani and F. tricinctum. In the 10 to 20°C temperature range, F. solani not only produced more severe illness than F. tricinctum, but it also created the longest lesions and had the highest disease prevalence. F. tricinctum did not develop diseases in seedlings that survived pre-emergence damping-off at 10°C. Temperature-dependent lesion length and disease incidence for F. solani increased from 10 to 20°C, but F. tricinctum-induced lesion length and disease prevalence reduced as temperatures increased from 15 to 20°C [95, 96].

According to Delgado-Baquerizo et al. [97], temperature has a positive correlation with the relative abundance of prevalent plant pathogens, and Spearman correlations exist between variables in the environment and the relative abundance of prevalent fungal plant pathogens at the genus level (n=235). According to a US experiment aimed at determining the impact of soil temperature on Helminthosporium sativum infection of barley and wheat, at a temperature below 16°C, barley was more freely attacked than wheat. In contrast, the most susceptible barley variety was attacked [98].

4.5. Altered Soil Structure

Since soil structure defines how soil particles are arranged into aggregates, any change in this structure induced by soil erosion or soil compaction leads to reduced soil porosity and aeration [99]. When soil porosity is reduced, it limits soil aeration and water infiltration, which in turn favors anaerobic pathogens. Fusarium wilts caused by Fusarium species are a good example of a disease that is highly severe in poorly aerated soil [100].

4.5.1. Soil Compaction

According to Bogunovic et al. [101], soil compaction is caused by agricultural practices such as overgrazing and the use of large machinery for growing crops and management, which reduce the size of the soil pores. Compacted soil decreases the flow of water and air, leading to anaerobic conditions that are favorable for facultative and anaerobic soil-borne diseases like Fusarium [102-105]. Additionally, inadequate root penetration in compacted soils exposes plants to soil-borne diseases [106].

In the compacted and overgrazed soils, nematode infestations (Meloidogyne spp.) are reported to be higher. This is attributable to soil compaction, which leads to a reduced number of beneficial nematodes while leaving the harmful nematodes unaffected [107, 108].

4.5.2. Soil Erosion

When the soil is eroded by agents of erosion such as wind and water, it carries away the topsoil, a layer that is mostly enriched with organic matter, leaving the porous subsoil with poor water retention, thus favoring pathogen survival and spread [6, 109]. For instance, the disease caused by Phytophthora species has been reported to be more severe in eroded soils due to waterlogging conditions. Another example is bacterial wilt, which has been reported to increase dramatically in areas where soil erosion and degraded soils predominate. In Southwest Asia, there is a high vulnerability of crops to bacteria because of the extensive deforestation that has been done for establishing palm oil plantations [110-113].

4.5.3. Reduced Organic Matter

Due to its ability to bond to the soil, organic matter in the soil is essential to maintaining proper soil structure [114]. Degraded soils often have lower levels of organic matter, thus rendering poor soil structure. Poor soil structure leads to increased susceptibility to erosion and compaction. This, in turn, creates favourable conditions for pathogens like Fusarium, which thrive in poorly structured soils [115-119].

4.5.4. Waterlogging and Poor Drainage

Altered soil structure often leads to poor drainage, resulting in waterlogged conditions. Waterlogged soils create an anaerobic environment that can promote the growth of pathogens like Phytophthora and Pythium. These pathogens thrive in saturated soils and can cause severe root diseases [120-122].

4.5.5. Crusting

In some soils, degradation may be accompanied by soil crusting. The crust formed significantly reduces the water infiltration and aeration. In such conditions, there will be poor seedling emergence and root development, which will render the young plants susceptible to the damping-off caused by Pythium species [123-125].

4.5.6. Loss of Soil Aggregates

Healthy soils have aggregates formed by the binding of soil particles with organic matter and microbial exudates. These aggregates create a stable soil structure with ample pore spaces. Land degradation, particularly through intensive farming and chemical use, can break down these aggregates, leading to a more homogenous and compact soil matrix. This breakdown not only reduces the soil's resilience to erosion but also diminishes its ability to support a diverse microbial community that can suppress pathogens [123, 125-127].

4.5.7. Reduced Water Infiltration and Retention

Poor soil structure restricts water infiltration and aeration capacity, thus causing waterlogged conditions. Under waterlogging conditions, soil-borne pathogens such as Phytophthora [128]. On the other hand, Shahi et al. [129] when dry conditions prevail in the soil, plants become more susceptible to Fusarium wilt. Poor water management in degraded soils can thus create fluctuating moisture conditions that favor different pathogens at different times, challenging disease control efforts [130].

4.6. Nutrition Imbalance

Practices such as overuse of chemicals, deforestation, and over-farming compromise soil health, consequently leading to an increase in the susceptibility of the plants to diseases [131, 132]. A balanced level of nutrients is required for proper plant health and resistance to diseases. In most degraded soils, plant nutrients are deficient, which weakens the plant and renders it susceptible to infection by soil-borne pathogens such as Fusarium spp [133, 134].

Among other factors, the richness of microbes in the soil is dependent on nutrient availability as the principal factor; therefore, when the soil is deficient in some nutrients, especially the macronutrients, it negatively affects the richness of microbes in terms of number and species of beneficial microorganisms that can fight and suppress the pathogenic microbes [135].

However, nutrient imbalances, such as excessive nitrogen from over-fertilization, can disrupt this microbial balance. On the other hand, high nitrogen levels can promote the growth of pathogenic fungi like Pythium, while reducing the populations of beneficial microbes that help control these pathogens [136, 137].

Some cases of soil-borne pathogens that can survive in nutrient-rich soils have been reported. A good example is (Meloidogyne spp.), which causes significant damage to plant roots and can thrive well in nutrient-imbalanced soils, such as in soils with high levels of phosphorus [138]. Similarly, Verticillium dahliae and V. albo-atrum, which cause verticillium wilt in tomato and potato fields, become more prevalent in soils with an excess amount of potassium, thus increasing the severity of the diseases. These imbalances create an environment conducive to pathogen survival and spread [139, 140].

4.7. Microclimate Changes

The microclimate refers to the climatic conditions in a small, specific area that can differ significantly from the general climate of the region [141].

Studies have shown that the microclimate of an area can be affected due to land degradation, which in turn can increase the severity of soil-borne disease [142]. The loss of vegetation cover and soil organic matter, which consequently leads to elevated soil temperature is aggravated by soil degradation [143, 144].

This is because vegetation helps to moderate temperatures by providing shade and retaining moisture. When this cover is disrupted, soils can become much hotter during the day and significantly cooler at night. A good example is Rhizoctonia solani, which causes root rot and becomes more severe in heat-stressed plants vulnerable to pathogens [145, 146].

Similarly, land degradation may lead to poor soil drainage, which directly affects the humidity levels in the soils, which may become lower during dry seasons and higher during the wet seasons. These fluctuating humidity levels can create favourable conditions for various pathogens. High humidity levels can promote the growth of fungal pathogens like Phytophthora, which thrive in moist environments, while low humidity can stress plants and make them more susceptible to root diseases [12, 13, 147]. The removal of vegetation through deforestation or overgrazing can alter wind patterns at the micro level. With fewer barriers to block and slow down the wind, degraded lands can experience stronger winds. These winds can dry out the soil, disperse soil particles, and transport soil-borne pathogens to new areas. For instance, the dispersal of nematode cysts by wind can lead to the spread of nematode infestations in previously unaffected areas [15, 16].

Moreover, the loss of vegetation cover, which exposes the soil to increased soil radiation, is a characteristic of degraded soils. This may result in hotter soil temperatures and greater rates of evaporation, which would further reduce soil moisture content. But also, it was claimed by Qadir et al. [148] high levels of solar radiation can also damage plant tissues, making them more susceptible to pathogens. For example, sunscald on the stems and fruits of plants can create entry points for pathogens like Botrytis cinerea, which causes grey mould. Table 5 presents examples of soil-borne plant diseases that develop following micro-climate changes in degraded soils.

Table 5. Examples of soil-borne plant diseases developing due to a change in microclimate in degraded soils.

Disease	Pathogen	Crops affected	The microclimate element affected	Causes	The region affected in the world	Reference
Verticillium wilt	*Verticillium dahliae*	Tomatoes and eggplants.	Increased temperature fluctuations and lower humidity levels.	Removal of olive groves for urban development	Mediterranean region	Gitari, et al. [18]
Powdery mildew	*Erysiphe spp.*	Wheat and barley	High humidity and moderate temperatures	Removal of olive groves for urban development contributed to these microclimate changes.	Midwest United States	Lehman, et al. [19]
Fusarium Head Blight	*Fusarium graminearum*	Wheat	Increased temperature extremes and reduced humidity.	Deforestation and intensive farming	In the parts of Canada	Bastida, et al. [20]
Late Blight	*Phytophthora infestans*	Tomatoes	Cool and moist conditions	The removal of vegetation for agriculture	In the highlands of East Africa	Menta [21]
Southern Blight	*Sclerotium rolfsii*	Peanuts, beans, and tomatoes	Higher soil temperatures and reduced organic matter	The loss of vegetation and organic matter	Southern United States, southern blight has become more prevalent.	Usharani, et al. [22]; Garcia Gonzalez [125]; Le Bissonnais [126] and Xie, et al. [127]

5. Strategies for the Management of Soil-Borne Plant Diseases Under Degraded Soils

Because soil-borne plant diseases significantly limit crop production, especially in degraded soils where nutrient depletion and structural deterioration exacerbate their impact, it is critical for farmers to adopt management practices that effectively manage the diseases, restore soil health, and ensure sustainable crop production [149]. These remedies take a multimodal approach, incorporating biological, cultural, and chemical methods to attenuate disease severity and improve plant resistance [150] (Table 6).

Table 6. Strategies for the management of soil-borne plant diseases under degraded soils.

Diseases management strategy	Description	Example of disease-managed	Reference (s)
Soil amendment	Addition of SOM to improve soil health and suppress plant soil-borne pathogens.	Reduction of Fusarium wilt incidence in tomato fields	De Corato [151] and Bonilla, et al. [152]
Crop rotation and diversification	To disrupt the life cycles of soil-borne pathogens	Management of damping-off disease caused by *Rhizoctonia solani* in solanaceous crops	Akber, et al. [153]; Narayanasamy [154] and Dutta [155]
Use of resistant crop varieties	To reduce disease severity and improve yield	Management of Verticillium wilt disease caused by *Verticillium dahliae* in potato.	Pasche, et al. [156]; Munyaneza and Bizimungu [157] and Sowik, et al. [158]
Use of antagonistic microorganisms (Biological control)	To suppress pathogenic soil microorganisms	Use of Trichoderma spp. to effectively control Fusarium and Rhizoctonia in crops	Boro, et al. [159]; Ali and Nadarajah [160]; Suprapta [161]; Verma, et al. [162] and Adnan, et al. [163]
Soil solarization	Helps to concentrate solar radiation, which raises the temperature to kill the pathogenic microorganisms.	Management of Pythium and *Phytophthora spp*. responsible for causing root rot diseases	Elshahawy and Saied [164]; Bennett, et al. [165] and Sharma, et al. [166]
Anaerobic Soil Disinfection (ASD)	It involves saturating the soil with water and covering it to create anaerobic conditions that kill the soil-borne pathogens.	Significant reduction in disease incidence in crops such as strawberries and tomatoes caused by *Phythium spp* and *Fusarium spp.*	Priyashantha and Attanayake [167]; Hamal [168] and Khadka [169]
Biofumigation	This technique involves incorporating specific plant species, such as Brassica crops, into the soil to suppress pathogens. The crop species release bioactive compounds that inhibit the growth of pathogens.	Significant reduction of Fusarium wilt incidence in the tomato field after incorporation of cover crops, leading to healthier growth and higher yields	Thru Ppoyil [170] and Awrey [171]
Integrated Disease Management (IDM)	A combination of biological methods of control, the use of resistant varieties, and cultural methods such as crop rotation.	Management of Fusarium wilt caused by growing *Fusarium oxysporum f.sp. lycopersici-resistant* tomato varieties, rotation of tomato with common beans, addition of organic manure, and field sanitation.	Manici, et al. [136]; Katan [31]; Patil, et al. [172] and Baysal-Gurel, et al. [173]

6. Future Directives for the Management of Soil-Borne Diseases in Degraded Soils

The use of sustainable agriculture methods to improve soil health and microbial diversity is essential. Biofumigation is a potential technology that involves introducing Brassica family plants into the soil. These plants synthesize glucosinolates, which degrade into beneficial substances that protect against diseases, including Fusarium and Rhizoctonia. Recent research shows that biofumigation considerably reduces disease incidence in crops such as tomatoes and strawberries, resulting in higher yields and plant health [174-176].

Vida et al. [177] demonstrated that using organic amendments like compost improves soil microbial diversity, which is critical for disease suppression. For example, compost application has effectively reduced Verticillium dahliae populations in strawberry fields, resulting in healthier plants and greater fruit quality.

Anaerobic Soil Disinfestation (ASD) is an effective option for controlling soil-borne diseases without the use of chemicals. ASD involves saturating the soil and covering it to create anaerobic conditions, which significantly reduce hazardous pathogen populations [168, 178]. For example, ASD has been shown to effectively manage Fusarium and Pythium in a variety of crops, resulting in healthier plants and higher yields. Furthermore, coupling ASD with organic amendments improves its efficacy since organic matter provides a carbon source for beneficial microbial communities during the anaerobic phase [179, 180]. According to Gioia et al. [181], an integrated approach not only helps manage current diseases but also enhances the long-term resilience of degraded soils, making them more than capable of enduring future pathogen pressures and enhancing overall soil health.

7. Conclusion

The degraded soils are characterized by conditions that may influence the growth, movement, and survival of pathogens that cause important soil-borne diseases in crops, thus increasing pathogen virulence, disease, and severity. Additionally, in degraded soil, there is a loss of beneficial microbes, such as antagonists that inhibit the growth of plant pathogens. Furthermore, plants in degraded soil are weakened by unfavorable factors, including low soil nutrients, moisture, temperature, and pH, thus rendering them vulnerable to infections by pathogens. On the other hand, plant pathogens have a greater capability to survive extreme conditions or may undergo some modification to survive in degraded soils better than beneficial microbes, thus they can infect in such situations. Since managing severe soil-borne diseases is much trickier, a sustainable disease management approach would be the best option. Sustainable techniques such as minimum tillage, zero tillage, conservation agriculture, proper fertilization, proper grazing, agroforestry, avoiding the use of heavy equipment, use of salt-free water for irrigating crops, water for irrigation, afforestation, re-afforestation, and other activities that reduce the occurrence of climate change need to be adopted to curb the impacts of soil degradation.

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