Chapter

Soil Biodiversity as a Key Sponsor of Regenerative Agriculture

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Abstract

Increasing knowledge and literacy around soil biodiversity is essential to discover and implement biological solutions for the discouraging challenges people face in agriculture and human wellbeing. Therefore, this review was done to get an insight into the awareness and understanding of the contribution of soil biodiversity to regenerative agriculture. The review was done by referring to the latest different research findings; reports, working guidelines, as well as knowledge shared from different soil biodiversity conferences and webinar discussion points. The review disclosed that to meet the increasing demand for food for the ever-increasing global population and the 2030 sustainable development goals, regenerating the already degraded lands through regenerative agriculture principles and practices is vitally important. The findings and report documents showed that soil biodiversity facilitates the regenerative agriculture system as soil organisms are using as soil health improvement machines, a remediates for soil and water pollution, a fertilizer, pesticide, as a means of carbon sink, and used in the pharmaceutical industry to discover new drugs and vaccines for animal and human health. Moreover, the meta-analysis publicized that the consideration and use of soil biodiversity in the regenerative agriculture system have promising results although little is known about the role of those soil organisms in the ecosystem due to the presence of knowledge gap and complexity of relationships in the soil system. Therefore, furthermore, attention should be given to the discoveries of soil biodiversity to use them as a natured based solution for regenerative agriculture in the 21st century and to meet the 2030 sustainable development goals.

Keywords: Bio-fertilizer, Soil biodiversity, Ethiopia, Holistic systems approach, Nature-based solution

1. Introduction

Agriculture is a soil-based industry that is heavily burdened to feed the increasing global population. And soil has been described as "the fragile living skin of the Earth", but yet both its aliveness and fragility have often been ignored in the expansion of agriculture across the face of the globe [1]. Since it is a pivotal component in a global nexus of soil, water, air, and energy, how we treat the soil can impact massively on agriculture and climate change. Soils constitute one of the largest reservoirs of biodiversity on Earth and soil organisms are the source of key ecological functions and services that support agriculture, including soil conservation, water cycling, pest and disease regulation, carbon sequestration, and nitrogen fixation [2].

Currently, sustainable agriculture which is expressed as "industrialized agriculture" [3] relies on monoculture cropping, increasing use of mechanization, the application of synthetic fertilizers, pesticides, and herbicides, along with liberal government subsidies. Although this approach can be considered successful, in that it has managed to feed a massively rising human population [4], a range of environmental and social burdens have also been incurred, including erosion, soil nutrient depletion and contamination; loss of water resources and biodiversity, loss of forests and desertification; human labor abuses; and naturally the decline of the traditional farming practices.

In Ethiopia, one of the most singly destructive factors in farming is land resource degradation [5]. Almost all the land resource balances in Ethiopia show a soil nutrient deficit, water and soils are eroded, forests are depleted, wildlife and biodiversities are disturbed; representing a loss of yield and quality for consumption and causes climate change. Once the land becomes degraded, fertility and health of the soil are lost; farmers suffer extreme losses in very low yields on their farms. Such losses are projected in an environment sensitive to climate change, cost of living, and starvation. Hence, urgent steps are needed to avoid this and regenerate the depleted resources.

Therefore, there is no need of sustaining the already degraded land resources, rather regenerating them and formulating sustainable agriculture. The agricultural revolution in Ethiopia is wishing for effective solutions which are fundamental to land management and agricultural practices. Regenerative Agriculture which defined as "*a holistic systems approach to agriculture that encourages continual on-farm innovation for environmental, social and economic wellbeing and improves the land resources it uses, rather than destroying or depleting them* [6, 7] is crucial for successful land management and agricultural practices.

Regenerative agriculture at its core has the intention to improve the health of soil or to restore highly degraded soil, which symbiotically enhances the quality of water, vegetation, and land productivity [8, 9]. Essentially, regenerative agriculture depends upon soil biodiversity and there may be no soil biodiversity without practices of regenerative agriculture; they have evolved together. By using methods of regenerative agriculture, it is possible not only to increase the amount of soil organic carbon in existing soils but to build new soils through attenuate the rate of soil erosion, restoration of the soil food web, improvement of soil fertility, and the activities of plants, animals, insects, fungi, bacteria, and humans too, all play a part in the formation of soil [1]. Hence, for the future scenarios challenging the agricultural sector such as soil degradation, increasing food demand, climate change, water scarcity, global soil biodiversity education and consideration of soil biology as a long term solution is needed to realize the full benefits of regenerative agriculture and respond to the needs of farmers and consumers relating to agriculture and land management.

Similarly, soil biodiversity plays a role in the formation of soil and enhances the ecosystem functions, services [10], and intern production and productivity of regenerative agriculture. Thus, this would lead to the consideration of soil biodiversity (activities of plant roots, animals, insects, fungi, bacteria ...) as nature-based solutions in the restoration of the soil food web, improvement of soil health and fertility, agricultural productivity, while locking-up carbon from the atmosphere.

Increased education and awareness are key strategies in ensuring that soil biodiversity is no longer out of sight, out of mind. As agricultural soils are under threat, there is a need to promote interactions between scientists, policymakers, and the general public to transfer and implement scientific findings of the benefits of soil biodiversity and ways to restore and conserve it [11]. These organizations and Elizabeth *et al*., [12] also asserted that soil biodiversity is critical for soil functioning and plant production but has been largely ignored in global, regional, and national policies that address land management, food security, climate change, loss of biodiversity, and desertification.

And finally, increasing knowledge and literacy, and passion, particularly around soil biodiversity is essential to draw on the diverse community of stakeholders required to discover and implement biological solutions for the daunting challenges people face in climate change, agriculture, ecosystem restoration, environmental pollution, and human health. Once more, this review is the place to get awareness and understanding of the contribution of soil biodiversity to regenerative agriculture.

2. Methodology

The review was done by a literature search and document sourcing using an online search in major websites that provide access to scientific research, like Research Gate, Science Direct, and Google Scholar to referring different research findings; reports, and working guidelines, as well as knowledge shared from different soil biodiversity conferences and webinar discussion points. Besides, citations in key papers were followed to identify additional relevant Articles and synthesize relevant peer-reviewed articles and related literature. Hence, it may represent a general diversity of regions and nations and provides a wealth of principles, examples, actions, and solutions to bring soil biodiversity into the light of regenerative agriculture.

3. Contribution of soil biodiversity for regenerative agriculture

3.1 Regenerative agriculture: overview

Current conventional farming methods are resulting in the loss of fertile soil and biodiversity. According to Maria-Helena Semedo of the FAO, as cited by Chris [13], the world could run out of topsoil in about 60 years if we continue at current rates of soil destruction, as now about a third of the world's soil has already been degraded. This affects the earth's ability of food production, water filtering, carbon absorption, and farmers will no longer have enough arable topsoil to feed the growing world population. There might be a duty to transit towards regenerative agricultural practices.

Regenerative Agriculture is a system of farming principles and practices that increases biodiversity, enriches soils, improves watersheds, and enhances ecosystem services. The regenerative farming approach focuses on restoring soils that have been degraded by the industrial agricultural system. Its methods promote healthier ecosystems by rebuilding soil organic matter through holistic farming and grazing techniques. It enables the regeneration of land resources through the restoration of vegetation in a farm landscape using a high diversity of both annual and perennial crops [14, 15]. Moreover, it considers potential environmental and social impacts by eliminating the use of synthetic inputs and replacing them with site-specific management practices that maintain and increase long-term soil health, employment opportunities, and mitigation and adaptation to climate change.

André Leu [16] *who is the international director of Regeneration International* claims that transitioning 10–20% of agricultural production to the best practice of regenerative systems (Biologically Enhanced Agricultural Management) will sequester enough carbon dioxide (2.3 ppm of CO_2 per year) to reverse climate change and can change agriculture from being a major contributor to climate change to becoming a major solution. There is broad agreement that most regenerative agriculture practices are good for soil health and have other environmental benefits [17, 18].

Among the regenerative agriculture principles, No-till reduces soil erosion and encourages soil water infiltration [19]. Cover crops do the same, and can also reduce water pollution and contribute to reducing soil organic matter losses [20]. Diverse crop rotations can lower pesticide use [21] and reduce environmental pollution [22]. Focuses strongly on the environmental dimension of sustainability, which includes themes such as *enhance and improve soil health, optimize resource management, alleviate climate change, improve nutrient cycling* and *water quality and availability*, articulated by improving soil health through soil biological activities [23].

In the experimental research of La Canne and Lundgren [24], regenerative corn fields generate nearly twice the profit of conventionally managed cornfields. Similarly, their finding discloses the insecticide-treated cornfields had higher pest abundance than untreated, regenerative cornfields. Reports from Burgess *et al.* [25]; IPCC [26] and Lunn-Rockliffe *et al.* [27] have stated the fundamental importance of transitioning to more regenerative agriculture methods if the world needs to meet its climate change targets, food security demands, protect farmland and build a healthier food system.

For the goal of agricultural development in 3rd world countries, the future agricultural production systems should be designed to take better advantage of production resources found on the farm [28, 29]. While most of the regenerative and organic markets are in developed countries, developing countries like Ethiopia are becoming important suppliers, as regenerative agriculture practices are particularly suited for the conditions of their farmers, especially smallholders living in rainfed areas. However, yet Government agencies in developing countries cannot often make the corporate sector responsible for agricultural development and for preventing harm to the environment. According to reports made by EPAT [30], pesticides that are illegal in Europe are commonly applied throughout sub-Saharan Africa, owing to the industry's open-door pesticide policy. Farmers in resource-constrained and low potential areas of Ethiopia traditionally use few external inputs [31, 32] but many of the environmental, social, and economic benefits of land management, which translate into ecological intensification, are hampered by a lack of appropriate regenerative agriculture knowledge and skills.

Therefore, by understanding and implementing regenerative agriculture; considering soil biodiversity; the farming community will benefit from enhanced nitrogen fixation, greater total organic matter production, nature-based pest management, genetic tolerance to stress conditions, and higher levels of biological activity all contribute to resource use efficiency and quality of products.

3.2 Importance of soil biodiversity as a nature-based solution

The sustainable development goal (SDG) which were adopted by the United Nations in 2015 as a universal call to action to end poverty, protect the planet, and ensure that by 2030 all people enjoy peace and prosperity provides a renewed motivation for focusing on using soil biodiversity for food and nutrition, and for linking it to the sustainability of future agricultural systems [22]. Soil biodiversity is critical for human health, plant growth and support, water and climate regulation, and erosion and disease control so as considered to be a common ground for achieving sustainability goals [12]. Hence, management and conservation of life in the soil are integral to governmental actions to provide healthy food, reduce greenhouse gases, lessen desertification and soil erosion, and prevent disease thereby regenerating agriculture.

According to the FAO and ITPS's Status of the World's Soil Resources report (2015) [33], soil organic carbon and soil biodiversity are crucial to increase food availability and the soil's ability to buffer against climate change effects. On the International Day for Soil biologic diversity (May 22, 2020), Semedo, who's the Deputy Director-General for primary natural resources of FAO highlighted *"there is a need to change the way to connect with nature, and that we need healthy soils for a healthy planet with vibrant ecosystems that allow our food system to be more resilient"* [34]. And these invisible organisms react, they play a crucial role in sustaining our planet, provide our food, supporting our health, our ways of living, and also human wellbeing. The issues of soil biodiversity become under the sort of focus of FAO [11] and of course the science that the potential role of soil is not just for food production and food productivity, but more important is about the environmental services and about the health of the planet and how the microorganisms in the soil play a very critical role in regeneration system of agriculture.

However, unfortunately, most of the case has not been explored so far, the knowledge that has about the soil biodiversity and soil mechanism biodiversity is really near nothing compared to the whole complexity that we have in all parts of the board and the sort of ecosystem. The United Nations in 2015 declared the year to the interest as the International Year of Soils and has asked FAO and the Global Soil Partnership to carry out the first global soil biodiversity assessment which is now in progress.

In agriculture, we have high productivity on the open networks soil. So, soils with biodiversity open networks have more productivity than soil with closed networks. So in nature, plants that are growing in these open networking sites (high diversity soil systems) are capable of taking out nutrients in an efficient way. Of course, the point is that we should not only increase soil biodiversity but also that we have to talk to crop breeders and agronomists to get the right crop species and crop varieties to grow on these biodiverse soils.

On the webinar held among 1136 participants on May 22, 2020, by representing more than 140 countries, around 72% of the people said that soil biodiversity is applied especially in crop production in their country. Then some have in ecosystem restoration, pollution and bioremediation, food processing, and very few in terms of the medical sector [34].

Going forward, harnessing natural resources (microbes, fauna, flora) together with SOM, is considered as the most effective approach for a sustainable increase in farm productivity, mitigating climate change, and restoring degraded environments [11]. Further evidence of the relationships between soil biodiversity and functioning concerning soil organic carbon (SOC) dynamics and primary productivity at farm scales can help in bridging the knowledge gaps in the biotic regulation of SOC turnover and plant productivity. This will represent a major advancement, not only in ecology but also in agriculture in the context of global climate change and food security [35].

Soil microorganisms are critical for the maintenance of functions in both natural and managed soils because they are involved in several key processes, such as decomposition of SOM, soil structure formation, the cycling of carbon, nitrogen, phosphorus, and sulfur, and toxin removal. Moreover, microorganisms are fundamental in promoting plant growth and in suppressing soil-borne plant diseases [36]. There is mounting evidence that healthy soils may promote the suppression of plant diseases, pests, and pathogens mediated by soil biodiversity through predation, competition, and parasitism [37]. There is confirmation that belowground plant mutualists can ameliorate the impacts of pollution on plant growth [38], and earthworms have been suggested as useful facilitators of ecosystem services in abandoned mining areas [39] all those again might contribute to regenerate agriculture and improve productivity.

In general, everything that we eat, drink, breathe, clothes that we wear, and materials that we use pass through soil and soil biodiversity over and over again. Healthy soil with soil biodiversity at the center of sustainability programs is capable of providing most ecosystem services and therefore achieving compliance with SDGs and human well-being through regenerative agriculture [12]. Half of all sustainable development goals zero hunger, good health and wellbeing, clean water and sanitation, affordable clean energy, responsible consumption and production, climate action, and life on land (SDG-2, 3, 6, 7, 12, 13 and 15, respectively) depend on soil and regenerative agriculture [12].

There are currently several lines being explored for agriculture making better use of enhanced soil biodiversity: going back to wild crop relatives and how do they make use of microbiomes and can those traits be restored in current crops? And studying wild plant species along successional gradients to unravel how plants may be productive in high-diversity soils. Considering soil biodiversity also requires considering traits, interactions, and network structure (so, not only numbers). Soil biodiversity as a nature-based solution to enhance sustainability is possible, but it takes two to tango as it requires crops that can handle these soils [34].

Studies show that Arbuscular Mycorrhizal Fungi (AMF) can alleviate both biotic and abiotic stresses since they can contribute to restoring degraded lands and ecosystems via artificial inoculation, while they improve access of nutrients to plants. They also can regulate abiotic and biotic stresses to plants such as drought, salinity stress, heavy metal phyto-accumulation, and protection against pathogens [40, 41]. AMF are promising soil microorganisms that improve soil health through their influences on plant photosynthesis [42], nutrient transfer [43], root exudation [44], osmotic potentials [45], soil bacteria interactions [46], and soil structural improvement and as a trade-off nutrient uptake, disease control and phytoremediation [47, 48].

Microorganisms provide us many ecosystems service that results in soil health and consequently can be related to soil productivity and regenerating agriculture. For instance, nitrogen-fixing bacteria associate with legume roots fixes large amounts of nitrogen that are of pivotal importance for plant productivity. And the soil biodiversity is an important indicator of soil health in agriculture management [49].

Above all, agriculture needs a healthy full human resource to feed the increasing human population globally. Therefore, consideration of the roles of soil biodiversity on the medical sector or human health is necessary to use the full potentials of soil biodiversity for regenerating the ecosystem and agriculture. Soil microorganisms have an immense potential for the pharmaceutical industry because historically the discovery of numerous new drugs and vaccines; from well-known antibiotics like penicillin to bleomycin using for treating cancer and amphotericin for fungal infections and therapeutic measures for treating and controlling diseases comes from soil organisms [50]. As the systems of soil like that of the human system, the management aspect of the soil should be in line with biology rather than focussing on industrial chemistry.

3.3 Soil biodiversity dynamics

Soils support highly abundant and diverse communities of organisms that show a broad array of life histories and functional traits, and they range in body size from a few micrometers for some bacteria to several meters in length in the case of some earthworms. The soil microbial community is largely dominated by bacteria and fungi that account for most of the belowground biomass, roughly equal to 0.6 to 1.1% of soil organic C [51], and represent a biodiversity pool with estimated species richness of tens of thousands per gram soil [52]. Despite the importance of soil microorganisms, little is known about their distribution in the soil or how microbial community structure responds to changes in land management (**Tables 1** and **2**).

Taxon	Diversity per amount soil or area (taxonomic units indicated below)	Abundance (approximate)
Bacteria and Archaea	$100–9{,}000·cm^{-3}$	$4–20·10^{9}·cm^{-3}$
Fungi operational taxonomic units	$200–235\ m.g^{-1}$	$100\ m.g^{-1}$
AMF (species)	$10–20\ m^{-2}$	$81–111\ m.cm^{-3}$
Protists sequence	$150–1{,}200\ (0.25\ g)^{-1}$	$10^{4}–10^{7}·m^{-2}$
Nematodes (genera)	$10–100\ m^{-2}$	$2–90·10^{5}\ m^{-2}$
Enchytraeids	$1–15\ ha^{-1}$	$12{,}000–311{,}000\ m^{-2}$
Collembola	$20·m^{-2}$	$1–5\ 10^{4}\ m^{-2}$
Mites (Oribatida)	$100–150\ m^{-2}$	$1–10\ 10^{4}·\ m^{-2}$
Isopoda	$10–100\ m^{-2}$	$10 · m^{-2}$
Diplopoda	$10–2{,}500\ m^{-2}$	$110 · m^{2}$
Earthworms (Oligochaeta)	$10–15\ ha^{-1}$	$300 · m^{-2}$

Table 1.
Estimated diversity and abundance of soil taxa according to published work of Bardgett and van der Putten [53].

Organism size	Group	Known species	Estimated species	% described
	Vascular plants	350 700	400 000	88%
	Macrofauna			
	Earthworms	7 000*	30 000*	23%
	Ants	14 000	25 000–30 000	60–50%
	Termites	2 700	3 100	87%
	Mesofauna			
	Mites	40 000*	100 000	55%
	Collembalans	8 500*	50 000	17%
	Microfauna ad microorganisms			
	Nematodes	20 000–25 000*	1 000 000–10 000 000*	0.2–2.5%
	Protists	21 000*	7 000 000–70 000 000*	0.03–0.3%
	Fungi	97 000	1 500 000–5 100 000	1.9–6.5%
	Bacteria	15 000	>1 000 000	<1.5%

Asterisks indicate numbers of species that live in the soil.
Source: Orgiazzi et al. *[54].*

Table 2.
Known and estimated number of species of soil organisms and vascular plants organized according to size.

3.4 Biofertilizer and concern of soil biodiversity in Ethiopia

While field research on bio-fertilizers in Ethiopia dating back to the early 1980s by the Institute of Agricultural Research; bio-fertilizers did not become available for farmers until 2010. Later, the National Soil Testing Center (NSTC), Menagesha Biotech Industry (MBI) PLC, and the Ethiopian Institute of Agricultural Research (EIAR) have developed capacities to produce Rhizobia-based biofertilizers (**Table 3**). Currently, postgraduate students and different researchers in Ethiopia have played significant roles in research activities of Rhizobial inoculants collection, characterization, selection, evaluation and revealed the potential of the local isolates to serve as biofertilizers at a commercial level to increase the yield of different leguminous crops [56].

Jida and Assefa have collected 30 isolates of efficient nitrogen-fixing lentil-nodulating rhizobia from farmers' field soils in central and northern parts of Ethiopia and selected for symbiotically efficient ones, which possess plant growth-promoting characteristics. Under glasshouse conditions, they found characteristics such as IAA production in 36.7% and inorganic phosphate solubilization capacity in 16.7% [57].

Fekadu and Tesfaye [58] reported that *P. fluorescens* isolates showed plant growth-promoting (PGP) traits like phosphate-solubilization, siderophore (molecules that bind ferric iron with an extremely high affinity) production, hydrogen cyanide production, ammonia production, and indole acetic acid (IAA) production. Hence, these isolates have been used as biocontrol agents and plant growth-promoting rhizobacteria (PGPR). Similarly, Diriba, [59] reported that among wild Arabica coffee rhizosphere isolates, *Bacillus* and *Pseudomonas* spp. in particular showed remarkable inhibition against *Fusarium xylarioides*, *F. stilboides,* and *F. oxysporum* under in vitro conditions. The same author has also reported that a considerable number of wild Arabica coffee-associated rhizobacteria *(Pseudomonas, Bacillus*, *Azospirillum, and Rhizobium* produce siderophores.

The research outputs of Muluneh and Zinabu [60] revealed that the application of dried cyanobacteria on lettuce crop increased the number of leaves, leaf area, leaf length, fresh weight of the leaf, leaf dry weight, and the root dry weight of the lettuce by 159.5, 112.4, 80.8, 48, 137.5 and 110%, respectively, over their control. Tesfaye *et al.* [61] concluded that Azolla should be used as a biofertilizer for rice production in Ethiopia since it produces high biomass, is easy to manage and establish, increases the availability of macro and micronutrients (it scavenges K and recycles P and S), improves soil physical and chemical properties and fertilizer use efficiency, increases crop yield by 15–19% (by one incorporation) in Ethiopia and releases plant growth hormones and vitamins and does not attract rice pests. Some

Crop	Types of inoculant (rhizobia)	Crop	Types of inoculant (rhizobia)
Faba bean and Field pea	Rhizobia leguminosarum vicea	Common bean	*R. leguminosarum* phasoeli
Chickpea	Mesorhizobium cicer	Cowpea	*B. elkanii*
Soybean	*B. japonicum*	Groundnut	Rhizobium spp
Lentil	*R. leguminosarum*	Alfalfa	*E. meliloti*

Source: EIAR [55].

Table 3.
Rhizobia species in commercially available inoculants (biofertilizers) for legume crops in Ethiopia as of March 2014.

experimental works were done on the use of mycorrhizae on coffee production by Tadesse and Fassil [62] and, a promising result was obtained on the sufficiency of phosphorus particularly.

Although different studies have been undertaking on microbial inoculation trials of several pulse crops in Ethiopia, the knowledge and data regarding Ethiopian soil biodiversity are very limited. Of course, the country has a responsible institute (Ethiopian Biodiversity Institute) to ensure the country's biodiversity and the associated community knowledge for proper conservation and sustainable utilization [63]. However, the most focus is given to above-ground diversity, but the attention given for belowground diversity is less which leads to the presence of limited knowledge and data in soil biodiversity throughout the country.

In 2015 the "Ethiopia's National Biodiversity Strategy and Action Plan 2015-2020" were developed through the involvement of different stakeholders and higher officials. However, the attention and discussions given for soil biodiversity in the document as well as in the key not messages of higher officials look limited. Different state ministers who participated in the event was forwarded their message regarding Ethiopia's geographical, climatic, cultural, linguistic diversity and then about the above-ground diversity (plant, birds, mammals, fish …) but not on the diversity under their feet [64]. This reflects that society in general and policymakers, in particular, have neglected soil biodiversity; no attention was given to the large biodiversity pool stored belowground.

Generally, although some research findings were done and doing on the use of soil microbes as a biofertilizer in Ethiopia mainly by the academic group, there are no confidential estimates on the number of species, taxonomic groups, ecological functions and services, and interactions among soil organisms so far in Ethiopia. Moreover, there is no exact data on the level of threats to soil microbial genetic resources of the country. However, all factors affecting the ecosystem, plant, and animal biodiversity are believed to affect directly or indirectly the soil biodiversity base of the country [65]. Therefore, collecting, identifying, conserving, and knowing the status of soil biodiversity genetic resources of the country will be a forthcoming major task.

3.5 Challenges of soil biodiversity

The landmark FAO state about soil biodiversity for food and agriculture [66], the first-ever launch last year highlighted that associate biodiversity species living in around production seasons, particularly microorganisms and invertebrates, has never been documented. In many cases, there is a limited understanding of ecosystem function and service and consequently, the contribution of specific soil biodiversity components to the production systems is poorly understood [67]. This discloses that due to the presence of knowledge gap and complex interaction of soil life, soil biodiversity is increasingly under threat which results in changes in the composition of soil communities and loss of species, as well as the benefits they provide to all life. Therefore, governments and society all need to better understand the complexity of the interaction regarding all elements of future agriculture and the soils to think about resilience and food systems.

As a whole, soil degradation by erosion, land-use change, climate change, soil pollution, salinization, and sealing all threaten soil biodiversity by compromising or destroying the habitat of the soil biota. Management practices that reduce the deposition or persistence of organic matter in soils, or bypass biologically mediated nutrient cycling, also tend to reduce the size and complexity of soil communities. For instance, land-use intensification results in fewer functional groups of soil biota with fewer and taxonomically more closely related species [68]. Intensive agriculture and sealing of fertile lands due to urbanization can cause declines in abundance and species of soil biodiversity, making soil food webs less diverse [10, 69]. Wagg *et al.* [70] were also investigated this given recent observation that soil biodiversity is declining and that soil communities are changing upon land-use intensification. They showed that soil biodiversity loss and simplification of soil community composition impair multiple ecosystem functions, including plant diversity, decomposition, nutrient retention, and nutrient cycling. Louwagie [71] and Mujtar *et al.* [72] asserted that soil biodiversity tends to be greater in undisturbed natural lands as compared to cultivated fields.

Deforestation can alter the structure of soil communities and decrease species richness (including natural predators and pollinators) and leading to homogenization. Consequently, the area will have a reduction of ecosystem resilience due to organism imbalance, which can favor pests and disease outbreaks [73–75]. In the findings of Migliorini *et al.* [76] and Hong *et al.* [77] heavy metal, pollution can shift communities to become dominated by a few taxa that can tolerate, or even thrive with, high levels of chemical inputs with corresponding decreases in taxa abundant in unpolluted soils.

The introduction of all kinds of invasive alien species has harmed the aboveground biodiversity and the native soil biodiversity. The effects of invasive species in soil biodiversity vary depending on the species trophic position. Many invasive soil species are related to agricultural pests while certain species are introduced as biocontrol agents. Another example is the introduction of non-native earthworms (which are ecosystem engineers), but their invasions can cause cascading effects that impact plant communities, forest, carbon sequestration, and wildlife [78, 79].

3.6 Soil biodiversity management

Soil biodiversity is part of the biological resources of the agroecosystems and must be considered in national and international management decisions. As indicated in the publication of Lijbert *et al.* [80] the main management options for soil biodiversity comprise no-tillage, crop rotation, and organic matter management. Protecting existing natural areas, restoring degraded habitats, employing regenerative agricultural practices, and implementation urban biodiversity are important practices that support and sustain diverse soil communities and the functions and services they provide. Hence, adopting the use of intercrops, rotations, appropriate tillage methods, maintenance of soil cover and the incorporation of crop residues into the soil management practices favor beneficial soil biodiversity [81, 82].

Global Soil Partnership (GSP) was established in December 2012 to enhance collaboration and synergy of efforts for sustainable soil management, and to protect biodiversity through sustainable soil management. The GSP supports soil biodiversity enhancement through monitoring soil biodiversity; maintaining or enhancing soil organic matter levels; the regulation of authorization and use of pesticides in agricultural systems; the use of nitrogen-fixing leguminous species; restoring plant biodiversity and crop rotation. All those activities lead to sustainable soil management and higher and more stable productivity [83]. Over the past few years, there has been an increased interest in organic farming practices, which could have benefits for soil biodiversity, particularly owing to the reduced use of pesticides [84].

There is a need to celebrate discoveries about life under our feet, as well as to integrate knowledge about soil biodiversity into international policies. Understanding how limitations to agricultural production at various levels (social, cultural, economic, political, agronomic, biological, environmental, edaphic, genetic) can be overcome is essential, to predict possible management options for the conservation of soil biodiversity and regenerative agriculture. To restore soil biodiversity, there is a need to think about ecosystem management, first, and store by diversity and its multi-functionality that what they are doing and how they are interacting with other species.

4. Conclusion

Soil biodiversity is highly linked with the ecosystem functions and services in the atmosphere, hydrosphere, lithosphere, and biosphere; all those do have their contribution and influence on land resources and agriculture. The soil organisms are contributing to climate mitigation and adaptation, water infiltration, and purification, soil health improvements and productivity, and playing countless roles through modification of conditions for the proper plant, animal, and human health all those are intern involved in regenerative agriculture. So, regenerative agricultural practices and soil biodiversity are evolved together and they are important components for future agricultural directions both in developed and developing countries.

However, there are knowledge and skill gaps in the area of soil biodiversity particularly on invertebrates and soil microorganisms to taxonomically classify and determine the complex interaction among themselves and the environmental factors. Therefore, more attention should be given to the discoveries of soil biodiversity and moving beyond academic circles particularly in the developing countries, to use them as a natured based solution for regenerative agriculture in the 21st century and to meet the 2030 sustainable development goals.

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