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Stress and Struggles of Soil Biodiversity in the Global Innovative Technology for Food Sustainability

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ABSTRACT: Right from pre-historic times, humans have always looked for ways to explore the environment to satisfy basic economic needs such as food, clothing, and shelter. History is filled with various strategies borne out of this desire by humans to subdue the environment and judging from the drawbacks of some scientific advancements, one will be stating the obvious that the soil environment is at the receiving end of the brazen intrusion of nature. Regardless of the improvement in science we still experience environmental challenges such as soil pollution, soil degradation, drought, biodiversity loss, deforestation, etc. This article advocates that the advancement in science with the sole aim of food security and sustainability should not necessarily translate into stress and struggle for soil biodiversity.

KEYWORDS: Environment; agrochemicals; contamination; xenobiotics; chemical treatment

1. Introduction

Soil biodiversity makes up an ecosystem that supports nutrient cycling, contributes to remediate soil pollution, forms soil, and improves soil structure (Fig 1). Analysis of soil degradation and its effects on plants, human health, and soil biodiversity calls for concern as the soil environment is bombarded daily with xenobiotic substances partly orchestrated by human activities. The truth is this impasse is not just a rude reality but a call to give environmental issues a top priority and treat them as urgent. Scientific treatise has established that the continuous application of agrochemicals to improve crop yield and sustainability is one of the numerous causes of soil contamination. This was evident in a field investigation carried out by [1]. Results of the investigation revealed the successful restoration of soil health and improved crop yield using synthetic treatment options even though there were traces of metal deposits at the demonstration site. Hence, one consequence of this knee-jerk approach to food sustainability is the continuous cycle of soil biodiversity perturbations and human health-related challenges resulting from an overdose of exposure to xenobiotics.

In an earlier investigation, authors led a team of other researchers in developing an ecological risk assessment (ERA) in response to a pesticide incident in a farming community in Imo state southeast Nigeria. The highlight of working on such a project was understanding soil health perturbations in key parameters and how they affect public health and soil microbial population. Findings from the study support the theory that the soil environment is under the relentless onslaught by humans and the calamity that has already occurred from this reckless anthropogenic influence cannot be wished away. Meanwhile, a recent study as reported by the United Nations Environment Programme revealed that while there is a decline in some persistent pollutants such as DDT, there has been a corresponding increase in other pollutants detected at high levels in the air, water, soil, and various ecosystems. These pollutants are linked to cancer, liver damage, decreased fertility, etc. Therefore, the existential threat within the soil biota is a grim reality of the extent of soil deterioration staring us in the face and a significant threat to biodiversity.

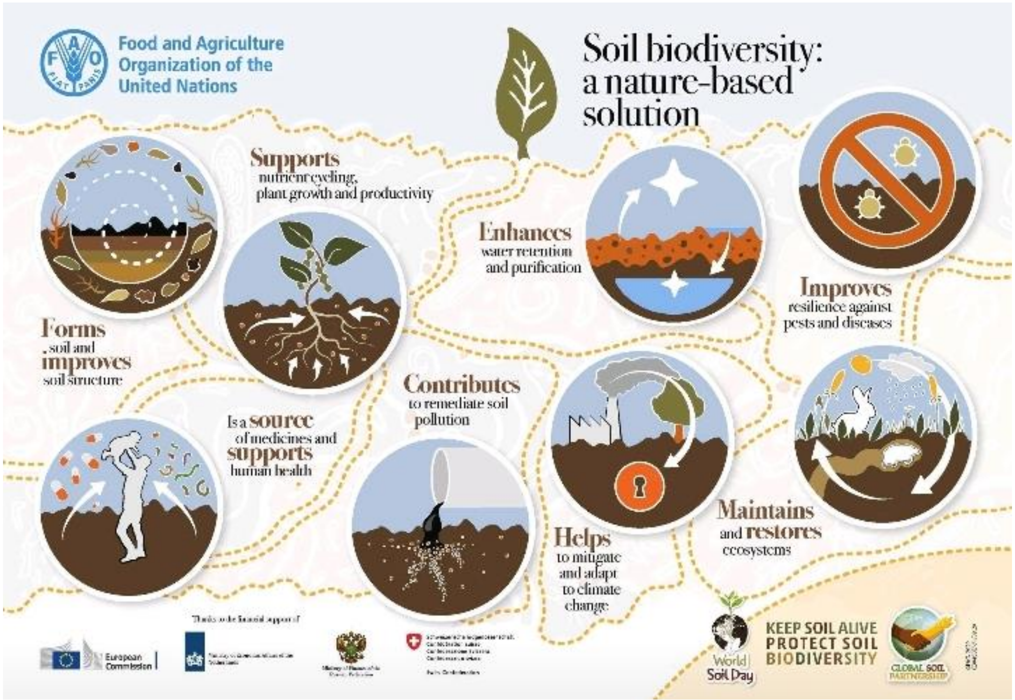


Figure 1. Infographic illustrating the benefits of soil biodiversity.

2. Soil Microorganisms in the Degradation Process

The soil has a rich biodiversity and together these organisms have established a functional ecosystem. However, human activities and natural phenomenon can disrupt this ecosystem. Microorganisms in the soil play a crucial role in sustaining the aboveground and belowground biodiversity by actively participating in the decomposition process. *Streptomycetes* for example are usually found in soil and water. Many species of these bacteria are important microorganisms involved in the decomposition of organic substrate in the soil thereby promoting soil health [2]. Studies have revealed that *streptomycetes* play an active role within the soil rhizosphere in the decaying of leaves and other organic compounds. They have a large repertoire of extracellular enzymes such as cellulases, xylanases, lignocellulase, and other enzymes which are involved in the decomposition of organic substrate [3].

Some byproducts of decomposition exercise include the production of soil nutrients like phosphorus, potassium, and nitrogen which equally contribute to soil health [4]. On the other hand, a stressed population of indigenous microorganisms may not be enough to degrade contaminants and when this happens, the once healthy and thriving soil will turn out to be a reservoir of contaminants. An earlier investigation also reported that soil microbial population is usually affected by the toxic concentration of contaminants in the soil [5]. The investigators demonstrated that agrochemicals such as fertilizers, fungicides, pesticides, and insecticides applied during cultivation have made the evaluation of ecological risk assessment (ERA) necessary. Different soil microorganisms have been identified scientifically to degrade organic compounds and contaminants within the soil ecosystem and they belong to various groups. *Pseudomonas putida* for example can degrade benzene and toluene compounds in the soil [6]. Also, the bacteria *Pseudomonas oleovorans* have been known to biotransform BTEX compounds in the soil into non-toxic products [7]. Similar investigation revealed that the growth of *Viribacillus salarius* isolated from saline soil was able to degrade benzene, toluene, and ethylbenzene compounds while using them as the sole carbon source [8].

3. Overview of heavy metals in arable soil

In a bid to rid crops of pests and increase yield, some farmers indiscriminately make use of chemical fertilizers and pesticides despite their adverse effects on soil biodiversity and human health [9]. Consequently, the soil has now turned out to be the main source of heavy metal deposits in the terrestrial ecosystem (Fig 2). Unlike other organic contaminants which are easily oxidized by microbes; most heavy metals do not undergo microbial degradation and they may persist for a long time [10, 11].

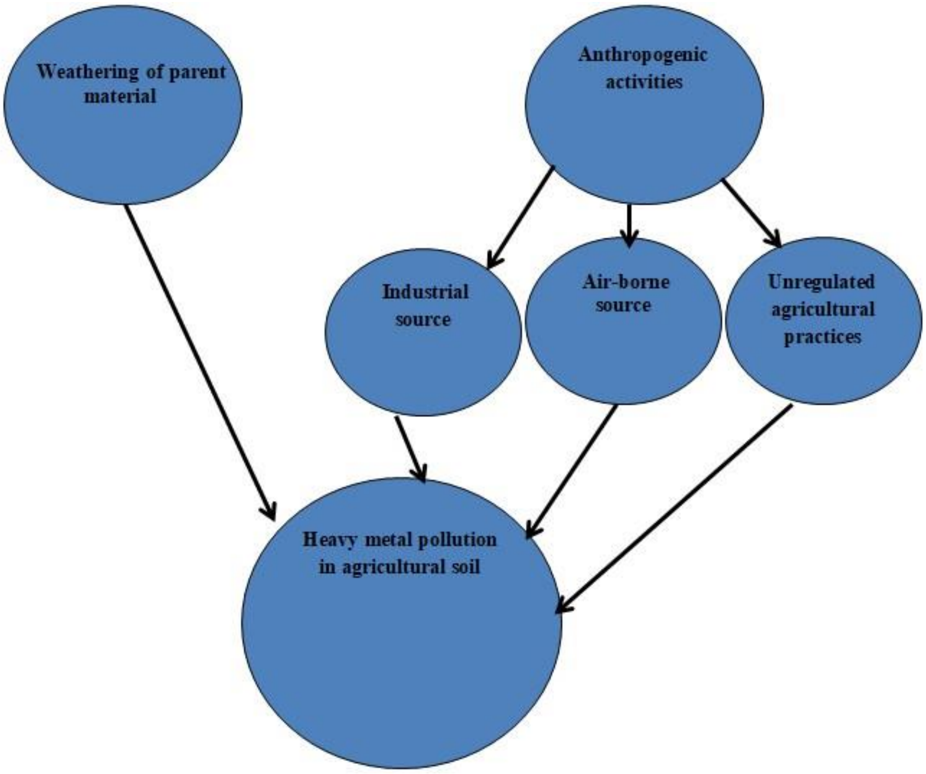


Figure 2. Flowchart depicting pathways through which heavy metals enter the soil.

4. Impacts of Heavy Toxic Metals on Soil Microorganisms

Soil perturbations caused by heavy metal contamination are one of the many challenges threatening the soil environment in many parts of the world [12]. In very high concentrations, toxic metals in the soil have been known to stress microbial populations thereby affecting biodiversity and destroying their ecosystem [13]. Soil biodiversity depends on the soil environment for its survival. For example, the mineralization of organic compounds by microorganisms releases nutrients such as phosphate and nitrate which can then be used by plants and other microorganisms for metabolism and growth. When the microorganisms decompose substrate with a C:N or C:P ratio below their threshold element ratio (TER), net mineralization occurs while substrate with a C:N or C:P ratio beyond their TER, N and P are taken up into the microbial biomass [14]. To further highlight the significance of soil functions in the ecosystem, microbial biomass and activity are usually higher in the rhizosphere than deep in the soil profile. This is because substrates such as root exudates are higher in the rhizosphere [15]. Given their role in the degradation process, soil microbes are significant in the arable soil ecosystem. Therefore, the continuous contamination with toxic heavy metals will affect microbial activities and eventually disrupt soil biodiversity.

5. Agricultural Practices as a Source of Arable Soil Contamination

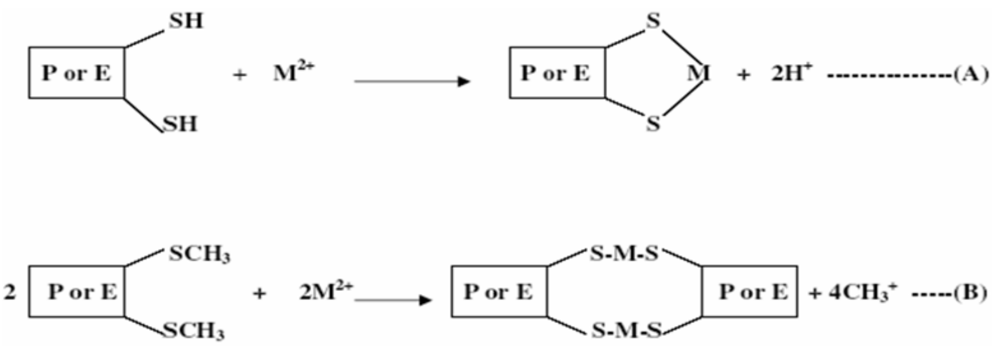
Studies have shown that naturally occurring heavy metals in the soil ecosystem which is a result of weathering of parent materials are usually at very low concentrations (less than 1000mg/kg) and are seldom toxic [16]. Meanwhile, another investigation revealed that heavy metals in contaminated soil resulting from anthropogenic sources tend to be more mobile than heavy metal contamination from natural sources [17]. Human activities such as the overuse or misuse of agrochemicals have caused most arable soil environments to accumulate one or more of these heavy metals thereby causing harm to human health, animals, plants, soil biodiversity, and the ecosystem in general [18]. In an attempt to increase yield, some farmers had to resort to the use of chemical fertilizers and pesticides even though these practices have adverse effects on soil microorganisms and physicochemical conditions (Fig 3). The environmental impact of these practices is evident in erosion, soil nutrient deficiency, pollution of surface and groundwater, etc.

Research has shown that excess nutrients not used up by plants may find their way into water bodies causing problems such as eutrophication [19]. Another investigation revealed that excess nutrients not utilized by plants e.g. phosphates and nitrates can cause algal bloom if leached to nearby water bodies thereby giving rise to hypoxia and in extreme cases, resulting in anoxia [20]. Several pesticides used in agriculture contain heavy metals in various concentrations. Studies have demonstrated that some phosphoric fertilizers normally add Cd and other toxic elements such as Hg and Pb to the soil [21]. These agrochemicals are applied as mitigation measures against pests to protect crops from diseases, damage, etc [22]. Pesticides control the biological, chemical, and physical dynamics in the soil. These factors can be grouped into those that affect microbial degradation and those that affect mobility involving plant uptake [23]. Previous scientific investigation revealed that 10% of chemical pesticides in the UK have compounds that contain Pb, Hg, Zn, or Cu [21]**.** Also, the control of some parasitic insects has been largely successful with the use of lead arsenate and arsenic-containing compounds [24]. The application of manure to arable soil may lead to the gradual accumulation of heavy metals such as Cd, Hg, Zn, Cu, etc in the soil [25]. Similar study revealed that Zn and Cu added to diets as growth enhancers in poultry may contaminate the soil [26]. The organic manures produced from birds on such a diet if continuously used over time may result in the accumulation of these metals in the soil which will eventually cause contamination [27].

Figure 3. Impacts of industrial agricultural practices on soil health and biodiversity.

6. Evaluation of biochemistry of heavy metals toxicity

The poisoning effects of heavy metals on organisms are usually more direct because they disrupt their biochemistry and metabolic activities. Available records show that when organisms are exposed to these toxic metals, they undergo chemical reactions and are converted into their stable oxidation states (Pb^{2+}, Zn^{2+}, and Cd^{2+}) where they react with biomolecules such as enzymes to produce strong chemical bonds [28]. The equations in Fig 4 show their reactions during bond formation with the sulphydryl groups (-SH) of cysteine and sulphur atoms of methionine ($-SCH_3$).



Key: P = Protein; E = Enzyme; M = Metal

Figure 4. Reaction equation showing bond formation between heavy metals and –SH of cystein and $–SCH_3$ of methionine.

The hydrogen atoms or the metal groups in the above case are replaced by the toxic metal and the enzymatic activities are disrupted. The new pseudo product formed which is a protein-metal then acts as a substrate thereby preventing further legitimate reaction. This scenario makes the enzyme incapacitated and unable to accommodate any other substrate except the metal leaves and this can only happen when it is utilized. If the metal is not utilized, the pseudo product formed will permanently block the enzyme and prevent it from initiating further bio-reactions. Therefore, the metal remains embedded in the tissue and will result in bio-dysfunctions of various gravities [29]. In addition, a toxic metallic ion in the organism can be conveniently replaced by another metallic ion. For example, Cd^{2+} can replace Zn^{2+} in some dehydrogenating enzymes, leading to cadmium toxicity [29]. In the process of inhibition, protein molecule structure can be rendered inactive or destroyed completely. For example, toxic As^{3+} occurs in herbicides, fungicides, and insecticides and can attack –SH groups in enzymes to inhibit their bioactivities as shown in Fig 5 [30].

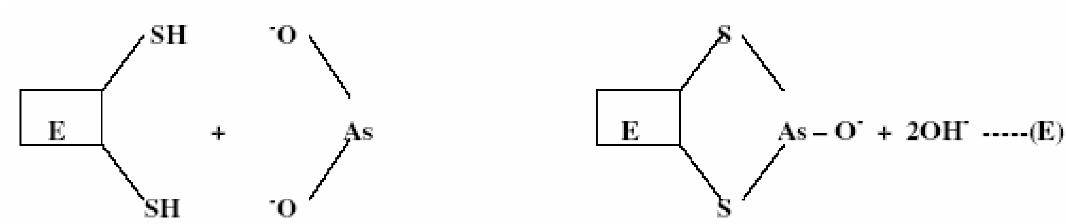


Figure 5. Reaction equation showing how toxic As^{3+} in agrochemicals attack –SH groups in enzymes.

The oxidation states of these metals remain their most toxic forms for example, Cd^{2+}, Pb^{2+}, and Ag^{+}. They form significant stable biotoxic compounds in organisms molecules while in their oxidation states and this can be very difficult to break down due to their bio-stability [27]. These biochemical reactions in living cells and the formation of toxic pseudo-compounds are indicative of the threats of heavy metals on soil organisms and the overall biodiversity.

Conclusions

From bacteria to fungi and even earthworms, the soil is teeming with life that keeps our planet healthy and thriving and this makes it one of nature’s most complex ecosystems. Therefore despite the global innovative technology for food sustainability, there is a need to promote and adopt sustainable management practices that would protect soil biodiversity. We must act fast to halt further soil contamination because protecting soil biodiversity is key to achieving food security.

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Competing Interest

The authors of this manuscript titled: “Stress and Struggles of Soil Biodiversity in the Global Innovative Technology for Food Sustainability” declare that there are no conflicts of interest regarding the publication of this paper.

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