SOIL IMPROVEMENT AND WATER CONSERVATION BIOTECHNOLOGY

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Soil Improvement and Water Conservation Biotechnology

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FOREWORD

More than one hundred years have passed since the Hungarian agricultural engineer Károly Ereki introduced the term "Biotechnology" to the world. This combination, perhaps strange at the time, between biology and technology, resulted from the observation and empirical knowledge of processes that provided us with goods, mainly associated with food products such as cheese, wine, bread, and beer. Products that, to this day, remain fundamental and in high demand.

However, according to historical and archaeological information, there is evidence from around 100 B.C. that the Teotihuacan culture already knew various biotechnological processes such as fermentation for the production of pulque (a traditional alcoholic drink from central Mexico), nixtamalization of corn, algae cultivation (spirulina), the use of natural dyes, as well as the medicinal use of plants and mushrooms. This shows that biotechnology, without being described as such, already played an important role in using living organisms and their metabolic processes for food production, as well as in medical, religious, and cultural matters.

Considering that humans have substantially increased their knowledge, a product of empirical understanding since the dawn of humanity, it is only natural that this knowledge has been perfected over time thanks to the progressive accumulation of observations and discoveries. Thanks to the development of the scientific method, which revolutionized the way we conduct scientific research in the modern era, significant growth and refinements have been achieved in the field of biotechnology, which includes a wide range of fields such as industry, agriculture, and the environment.

This compilation “Soil Improvement and Water Conservation Biotechnology” exemplifies, in a compelling manner, through perfectly structured examples, how the biotechnological approach applied to natural resources such as soil and water in Mexico has been successfully implemented. Although biotechnology is a controversial topic of great scientific and social interest, it is essential to apply a multidisciplinary and transdisciplinary approach given the complexities of biological systems for better understanding and resolution of environmental problems.

Finally, this book represents the culmination of an important and significant collective challenge: to face the complexity of addressing problems related to soil and water through a biotechnological approach in Mexico. We hope this work inspires future researchers and professionals to continue exploring and applying biotechnology for the well-being of our society and the environment.

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PREFACE

The significant issues of soil degradation and water scarcity represent some of the most crucial challenges currently confronting our planet. With the expansion of global populations and the escalating impact of climate change, the urgency for sustainable resolutions to these issues has never been more pronounced. The publication titled "Soil Improvement and Water Conservation Biotechnology" endeavors to tackle these challenges by investigating state-o--the-art biotechnological processes that have the potential to improve soil quality and optimize water utilization, particularly in ecosystems that are susceptible to adverse impacts.

The structure of this manuscript is designed to offer a comprehensive comprehension of the various facets of soil and water conservation. The initial sections establish the groundwork by analyzing the composition, functionality, and existing obstacles related to soil, with a specific emphasis on the distinctive attributes of soils located in the arid and semi-arid regions of Mexico. These areas, renowned for their severe conditions and limited water reserves, present distinct challenges and opportunities for the implementation of biotechnological interventions.

Subsequently, the publication explores sophisticated biotechnological strategies for soil and water conservation. Sections concerning 'omics' investigations uncover the intricate relationships between rhizosphere microorganisms and polluted soils, providing insights into how these relationships can be utilized for environmental rehabilitation. Techniques in bioengineering and the utilization of biofertilizers and biopesticides are presented as sustainable substitutes for mitigating soil degradation and enhancing agricultural output.

The discussion on water conservation biotechnology takes a prominent position in the latter segments of the book. Chapters dedicated to microalgae biotechnology, biological desalination, and the employment of microorganisms in wastewater treatment showcase inventive approaches for purifying and preserving water resources. The utilization of luminescent biosensors for pesticide detection and the significance of nanotechnology in water and soil conservation underscore the capacity of advanced technologies to transform environmental monitoring and governance.

In addition to furnishing a comprehensive theoretical insight, this publication is purposed to serve as an academic resource, providing practical methodologies directly linked to the topics covered in each chapter. Every chapter contains detailed explanations of practical methods and case studies that exemplify real-world applications of the technologies discussed. To further reinforce the material, there are review queries at the conclusion of each chapter, prompting readers to contemplate and engage with the content.

Acknowledging that technological progressions must be accompanied by ethical and societal considerations, the manuscript culminates with a section devoted to the ethical and societal dilemmas surrounding environmental biotechnology. This discourse stresses the significance of fair access to biotechnological resolutions and the necessity for community involvement in decision-making processes that impact their surroundings.

"Soil Improvement and Water Conservation Biotechnology" stands as a valuable reference for researchers, professionals, and scholars aiming to grasp and implement biotechnological innovations for sustainable soil and water administration. By amalgamating scientific expertise with pragmatic applications, this publication strives to contribute to the global endeavor to conserve our natural resources for forthcoming generations while equipping individuals with the essential tools for academic and occupational advancement.

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CHAPTER 1

Soil: Composition, Function, and Current Challenges

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Abstract: Soil embodies the fundamental basis for the sustenance of human existence on the planet. We are linked to its origin, evolution, and the set of processes that occur within its matrix. It forms close links with the water, energy, and food of all living beings that inhabit the planet. While it is customary to periodically conduct assessments of its physical, chemical, and biological characteristics, it is imperative to evaluate and identify the most effective research methodology to enhance the utility of the existing data. The current environmental challenges are setting the tone for the paradigm that must be followed for developing the tools and forming the working groups that will allow us to face the challenges that arise from an objective, scientific, and technological basis. In the current research endeavor, an examination is conducted on the fundamental components that confer significance to the soil, alongside an investigation of various concepts such as resilience and sustainability, which are integral to the foundational guidelines that ought to be considered as the preliminary framework in assessing the properties of the soil. Furthermore, the study emphasizes the development of bioindicators that facilitate the standardization of evaluative processes regarding the capabilities of ecosystem services and their associated attributes. The planet faces a dramatic environmental scenario with climate change as the most significant challenge. Along with water scarcity, soil salinity, and the acceleration of aridification, the scientific community must reorient efforts and work together; we can no longer be spectators.

Keywords: Bioindicators, Climate change, Ecosystems, Environmental services, Land aridification, Soil, Sustainability, Soil properties.

INTRODUCTION

One of the paramount characteristics of soil is its considerable variability, which consequently renders it exceedingly intricate due to the extensive interrelationship of systems that coalesce within its matrix. The genesis of soil can be attributed to

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Israel Valencia Quiroz (Ed.)

the intricate interplay of various environmental determinants, microbial organisms, geological constituents termed “parent material”, and topographical features, which are interconnected over extensive temporal spans; consequently, sedimentary layers of diverse depths are generated, consistently shaped by a predominant soil-forming agent. This agent imparts certain characteristics to the newly synthesized sediments, thereby endowing them with novel physical, chemical, and biological attributes.

As soil-forming factors are never homogeneous and are governed by the laws of thermodynamics, the variability of their properties is also influenced by the environmental conditions in which they develop. In this way, when the parent material that gives rise to the same specific type of sediment develops in two different environments, it forms two different types of soils; consequently, anisotropic processes and conditions vary according to the direction that the initial materials take as they continue to differentiate into several horizons parallel to the surface, which is called “Horizonization”. Although knowledge about pedogenesis and formation processes is extensive, the concept of soil continues to evolve as we attribute new meanings to it in our lives, regardless of the context or discipline in question. A study [1] initially proposed that there are two forms of components from which soils can be considered: i) based on the nature of their properties, and ii) based on their specific functions or land use. This elucidates our current assertion that fundamentally, soil constitutes a natural entity consisting of stratified layers (horizons) that are formed from weathered mineral constituents, organic substances, gaseous elements, and hydric components, having evolved as a vital element of both the “Earth” and the “ecosystems” [2].

Physical Components of Soil

Soil physical attributes, such as texture, structure, and moisture regime, are closely linked to climate and significantly impact plant growth and crop production [3, 4]. Drought, affecting about 57% of global soils, is influenced by soil texture, depth, and water-holding capacity [5]. Soil coarsening can alleviate precipitation constraints on vegetation growth in drylands [6]. Soil cracking, which is related to mineralogy, is another physical restriction affected by soil-water-atmosphere interactions [7]. Climate change is expected to increase aridity, leading to soil degradation and altered soil functions [8]. Arid soils, in particular, face challenges, such as low organic carbon, poor structure, and reduced biodiversity [9, 10].

Among physical soil properties, structure is the parameter that is considered most relevant to evaluate the productivity, sustainability, and degradation of ecosystems or agroecosystems [11]. Soil structures consist of a set of data, including aggregate stability and porosity [12]. The stability of aggregates is ascertained through an evaluation of a range of chemical, physical, and biological characteristics, along with agricultural management or conservation methodologies [13]. Soil porosity and structure significantly influence water retention and movement, which in turn affect soil quality and agricultural productivity [14, 15]. Land use and management practices impact soil structure, pore size distribution, and water retention properties [16, 17]. For instance, no-tillage practices generally improve soil aggregation and microporosity while reducing macroporosity [17]. Wetting and drying cycles can alter soil pore architecture and water retention characteristics [18, 19] and liming affects pore geometry and water retention in acid soils [20]. Soil structure has a significant impact on water infiltration, with correlations established between infiltration rates and structural properties [21]. Understanding these relationships is crucial for sustainable soil management and optimizing agricultural practices to maintain soil health and water availability for crops [22]. Studies carried out [23] on the micromorphology of aggregates and their relationship with environmental factors showed that different species of arbuscular mycorrhizal fungi have the capacity to generate different types of aggregates, so these tend to reconfigure indefinitely as the conditions vary. Arbuscular mycorrhizal fungi (AMF) play a crucial role in improving soil fertility and reducing erosion in agricultural ecosystems. It enhances nutrient uptake, particularly phosphorus, and improves soil structure [24]. AMF inoculation has been shown to significantly reduce erosion-induced soil nutrient losses, especially nitrogen and phosphorus, by enhancing plant nutrient uptake and decreasing runoff and sediment loss [25]. The synergistic interaction between AMF and associated microbiota contribute to soil fertility and plant health [26, 27]. Utilizing AMF and microbial consortia in agriculture can promote sustainable practices and improve crop yields [28]. In summary, the aforementioned attributes endow the soil with essential qualities necessary for preserving the optimal standards of its environmental functions.

Chemical Components of Soil

Chemical weathering of primary minerals is a fundamental process in soil formation, transforming rock components into stable substances in the surface environment [29]. This process is influenced by factors such as climate, topography, and parent material [29, 30]. Soil composition varies with weathering intensity, with clay-rich soils typically forming in warm climates where chemical weathering dominates [31]. In this manner, the byproducts of chemical weathering exhibit fundamental stability, provided that they persist within an environment analogous to that in which their formation transpired [32]. Currently, soil science considers three predominant origins of weathered materials, which then become soil: geological, organic, and anthropic. In a study [33], it is

CHAPTER 2

Soils of Mexican Deserts: Characteristics and Water Management Challenges

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Abstract: Mexico is home to two major deserts, the Chihuahuan and the Sonoran, which date back to the late Miocene. Both cover a vast region of northern Mexico and parts of the south of the USA. These deserts have been primarily shaped by recent tectonic forces and are characterized by tall mountain ranges that rise abruptly from alluvial plains. The landscapes include piedmont slopes, basin floors, alluvial deposits, closed drainage systems, and beaches. The soils are predominantly composed of alluviums, volcanic rocks, and isolated patches of sedimentary marine rocks. Intense wind erosion shapes the topography, creating sand dunes and impacting the biological productivity of ecosystems. The Sonoran Desert's climate is influenced by the surrounding mountains, which block moisture-laden air, resulting in rare winter frosts. In contrast, the Chihuahuan Desert experiences near- or below-freezing temperatures in its higher mountains. The vegetation in both deserts varies significantly due to differences in soil composition, topography, weather conditions, and soil age. Biological crusts play a crucial role in reducing erosion, trapping water and nutrients, and aiding in soil formation. Soils in desert environments typically consist of bare rock, varnished stone pavements, and coarse-weathered mantles. They undergo minimal weathering and leaching, resulting in coarser textures, shallow soil profiles, high concentrations of salts, and the accumulation of aeolian dust. These conditions pose challenges for providing ecosystem services such as flood regulation, water purification, climate regulation, and soil contaminant retention in urban areas located in deserts, thereby increasing vulnerability to climate change. Consequently, reconditioning soils in desert cities is essential before implementing any infrastructure to enhance ecosystem services.

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Keywords: Aeolian erosion, Biocrusts, Chihuahuan Desert, Dryness, Low profile development, Patchy vegetation, Sonoran Desert, Salts accumulation.

INTRODUCTION

Solar radiation strikes our planet most intensely near the Equator. Due to the Earth's tilt of approximately 23.5° relative to its orbit, the zone of maximum solar intensity shifts seasonally northwards towards the Tropic of Cancer and southwards towards the Tropic of Capricorn. Thus, the tropics (23°N to 23°S latitudes) form a warm belt where heat generates rising and unstable air. This warm air leads to the condensation of evaporated moisture from the oceans, resulting in heavy tropical rains. The dry air continues its movement away from the tropical belt and cools and descends around 25-30° latitude, where it forms dry conditions with a predominance of calm air and rare rainstorms. These corridors of stable atmosphere are known as the "horse" latitudes, where most of the world's major deserts are located [1].

Part of the Mexican territory is located around 32°N latitude, which is affected by the horse's northern latitude (30°). Additionally, Mexico's topography contributes significantly to the formation of drylands. When moisture-laden winds coming from the Pacific Ocean and the Gulf of Mexico encounter the continental mountain ranges of the Sierra Madre Occidental, they cool and condense into fog, feeding the montane cloud forests. After losing their moisture, these winds descend over the mountain crests, where they compress and warm, becoming hot and dry, which inhibits precipitation. In addition, Mexico's widening northern territory creates a barrier that prevents humid winds from penetrating inland, resulting in extreme climate conditions conducive to desert formation [2].

As a result, Mexico has 2 major deserts: the Chihuahuan and the Sonoran, which are relatively young on the continent, dating back to around 8 million years (late Miocene). Over time, the Sonoran Desert has fluctuated in size, expanding and contracting in response to climates (Pleistocene glacial and interglacial periods). Additionally, about 6 million years ago, the Baja California Peninsula (described as part of the Sonoran Desert) moved northwestward along the East Pacific Rise (later the San Andreas Fault). This isolation gave rise to much endemism [3].

The Sonoran Desert extends from the southwestern USA into northwestern Mexico (Sonora and Baja California), covering up to 324 300 km^2. As most of the desert lies on Mexican territory (71% or 230 635 km^2), it gets its name from the Mexican state of Sonora [4]. This Desert is subtropical, with complex geology, diverse soil types, and a wide diversity of species. It receives rainfall twice a year: light, prolonged rains in the winter and heavier downpours in the summer. This seasonal pattern helps alleviate drought stress, contributing to the desert's rich biodiversity. Frosting is virtually absent, allowing succulents and cacti to thrive [5].

The Chihuahuan Desert spans a vast region of northern Mexico (including territories from the states of Chihuahua, Coahuila, Durango, Zacatecas, San Luis Potosí, Nuevo León, and Tamaulipas), as well as parts of the southwestern USA, including west Texas, New Mexico, and Arizona. It accounts for 13% of the Mexican territory. The region is predominantly sedimentary, with extensive alluvial plains. Limestone is the predominant bedrock, with gypsum and igneous rocks in some areas. The desert contains distinctive white gypsum dunes, the largest of which is found in the White Sands National Monument in New Mexico [6].

The Chihuahuan Desert is located between two orographic barriers: the Sierra Madre Occidental to the West and the Sierra Madre Oriental to the East. It is characterized by elevations ranging from 400 meters along the Rio Grande to as high as 2,000 meters. This higher elevation contributes to cooler and more moist conditions compared to the Sonoran Desert. The combination of climate diversity and geological features contributes to a wide range of animal and plant life, particularly in grassland areas, although it is not as biologically diverse as the Sonoran Desert.

Factors in Soil Formation

Soils in the Sonoran and Chihuahuan Deserts are generally made of alluviums from the Pleistocene and Pliocene alluviums, volcanic rocks from the Cenozoic and Pleistocene (mainly granites, andesites, basalts, rhyolites, and tuffs), and, in isolated patches, sedimentary rocks of marine origin from the Cenozoic and the Mesozoic (mainly limestones, shales, marls, and calcareous sandstones) [7]. In areas close to the Sonoran Desert, rhyolitic alluvium, mixed alluvium derived from volcanic lithologies with subordinate metamorphic and limestone clasts, and mixed alluvium derived from rhyolite and monzonite have been identified as parent materials [8].

Parent material has a major influence on soil properties such as texture, composition, water retention, infiltration, aeration, and nutrient availability. For instance, soils derived from rhyolite (a slow-disintegrating extrusive igneous rock) contain more gravel and, therefore, have less plant-available water than soils derived from monzonite. Furthermore, under similar environmental conditions, limestone parent material inhibits the formation of argillic horizons, contrasting with soils derived from igneous rocks, where the argillic horizons tend to be common [9]. Regarding alluvium, when it is derived from limestone, it is usually rich in silt and has both a high carbonate content and higher proportions of mixed-

CHAPTER 3

Water in the Arid and Semi-Arid Zones of Mexico

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Abstract: This chapter analyzes the current situation and challenges faced by water management in the arid and semi-arid zones of Mexico. It examines the hydroclimatic characteristics of these regions, highlighting the importance of water for maintaining their unique ecosystems and supporting the rural populations that depend on it. Various water sources are studied, including groundwater aquifers, surface waters, rainwater harvesting, and treated wastewater. Each source is vital but presents distinct challenges for sustainable management, including the need for regulatory measures and innovative conservation techniques. Climate change and its effects, such as altered rainfall patterns, prolonged droughts, and rising temperatures, exacerbate water scarcity and threaten ecosystem stability, necessitating targeted adaptation and mitigation strategies tailored to local conditions. Innovative technologies and practices for water conservation and efficient use are discussed, such as advanced irrigation systems, water reuse, and real-time management through artificial intelligence and the Internet of Things. The chapter addresses the complexities of water use in agricultural, domestic, urban, and industrial sectors, with a focus on issues like overexploitation, pollution, climate change impacts, and conflicts over water use. It also underscores the significance of community-based approaches and the need for local engagement in achieving sustainable water management. Finally, the chapter provides an overview of strategies, policies, and legal frameworks aimed at promoting sustainable water

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management, drawing lessons from successful case studies and emphasizing the importance of integrated resource management, community participation, and international cooperation to tackle the multiple water challenges faced by these regions of Mexico.

Keywords: Water management, arid zones, semi-arid zones, Mexico, hydroclimatic characteristics, groundwater aquifers, surface water, rainwater harvesting, climate change, water scarcity.

INTRODUCTION

Water is essential for humanity and fundamental for life on our planet. Access to water is a basic human right and a central goal of global initiatives, making it crucial for social and economic development. However, its scarcity can lead to conflicts, underscoring the need for sustainable and equitable water management [1, 2]. Since 2007, UNEP has implemented water sustainability policies with an ecosystem approach, promoting rainwater harvesting as an accessible solution in regions with low precipitation [2]. Designing efficient rainwater harvesting and reuse programs, including the recycling of wastewater for green areas or agricultural production, is essential [3, 4]. In Mexico, where 60% of the territory is arid or semi-arid, sustainable water management is vital for agriculture and livestock [5]. Effective policies and rainwater harvesting practices are essential to ensure water availability [2 - 4].

The arid and semi-arid zones of Mexico face significant challenges due to water scarcity and extreme climatic conditions, affecting approximately forty million people who depend on drought-resistant crops such as maize and agave [5 - 7]. Effective water management essential for improving water availability and agricultural productivity while addressing issues like aquifer overexploitation and pollution [8, 9]. Climate change in Mexico is altering rainfall and temperature patterns, increasing extreme events, and affecting the availability of water resources [4, 10]. Recent droughts have stressed water systems, impacting aquifer recharge and surface water availability for agriculture [11 - 18]. The agricultural sector in these regions is particularly susceptible to the impacts of climate variability and extreme events [4, 19, 20].

Addressing these challenges requires the implementation of advanced irrigation technologies and sustainable agricultural practices, promotion of ecosystem restoration, and fostering of international collaboration to develop climate-resilient water management policies [17 - 21].

Current Water Situation in Mexico

Mexico's geographical location, divided into tropical and temperate climatic zones by the Tropic of Cancer, significantly influences its biological, cultural, and economic diversity. Approximately 52% of the territory is classified as arid or semi-arid, impacting natural resources and economic activities. Mexico encompasses both temperate and tropical climates, with deserts in the north and a tropical climate in the south. The average annual precipitation is 760 mm, with 65% falling in the summer and 35% in the winter. In 2024, the population is estimated to be 135,421,451, which increases pressure on water resources. These resources are unevenly distributed, leaving some regions facing severe scarcity [4, 22 - 29].

The arid and semi-arid zones of Mexico, primarily located in the north and centre of the country, experience low precipitation and high evapotranspiration, with elevated temperatures and irregular rainfall patterns. In the Sonoran Desert, annual precipitation ranges from 50 to 300 mm, while the Mexican Plateau receives between 300 and 500 mm. The Chihuahuan Desert receives between 150 and 400 mm annually. Although the mountains of the Mexican Plateau can recharge aquifers, the plains of Sonora and Chihuahua have a lower capacity for groundwater storage [5, 24, 30, 31].

In Mexico, annual water availability is 446,777 hm^3, although not all of it is used. CONAGUA regulates water use through the Public Water Rights Registry (REPDA), granting annual concessions of 266,560 hm^3. Agriculture accounts for 76.3% of consumptive water use, while domestic use represents 14.6%. In 2022, the national average water use was 19.5%, considered low pressure, though it varies by region: the Southern Border has a usage rate of 1.7%, while the Valley of Mexico faces extremely high pressure at 128.6%, indicating an unsustainable situation [24, 32]. Mexico faces serious water challenges due to climate change, aquifer overexploitation, and competition for water. Climate change has increased the frequency of droughts and floods, and 105 of the country's 653 aquifers are overexploited. Competition among agriculture, industry, and domestic use exacerbates the issue. Excessive extraction has lowered water tables and led to saline intrusion in coastal areas, while agricultural and industrial activities pollute surface and groundwater [4, 12, 13, 20, 33 - 35].

Water Sources in Arid and Semi-arid Zones

Overexploitation in areas such as the Valley of Mexico and Bajío leads to the decline of water tables and land subsidence, necessitating regulatory and monitoring policies [5, 32, 33]. Rivers, lakes, and reservoirs, including the Cutzamala System, are essential resources, though their availability fluctuates

CHAPTER 4

'OMICS' Studies on Rhizosphere-Microorganism Interactions in Soils

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Abstract: Soil is an ecosystem in which millions of microorganisms live and interact with plant roots. It has phytoremediation properties, sequestering pollutants such as heavy metals (cadmium, lead, and sulfur, among others), microplastics, and a great diversity of products of anthropogenic origin. Recently, the indiscriminate discharge of pharmaceuticals into public sewage systems has become a major concern, resulting in a public health problem due to the multi-resistance of clinically important bacteria and fungi to these pharmaceuticals. Similarly, the constant use of soil for agriculture, as well as the application of pesticides to combat economically important pests, has damaged both the native soil microbiome and impoverished both the biotic and abiotic properties of the soil. This issue is further exacerbated by the detrimental effects of global climate change. This has led to the search for methods to detoxify soils and reduce the deleterious effects of pollutants. Thus, omics tools, such as metabolomics, metagenomics, proteomics, genomics, and transcriptomics, detect the presence of these pollutants and develop detoxification strategies. For example, in soils exposed to copper (Cu), the earthworm *Eisenia fetida* induces metabolites such as pyruvic acid. In China, the restoration of black soils is possible due to the metabolomic profiling of 287 detected metabolites, which permitted the identification of specific biomarker metabolites that serve for the restoration of degraded soil. Thus, omics tools have become indispensable for the monitoring, diagnosis, and remediation of soils with a high rate of alteration due to anthropogenic activities.

Keywords: Agriculture soils, Contaminated soils, Omics tools, Rhizosphere-microorganism interactions.

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INTRODUCTION

Soil is a vital resource for plant sustenance and provides a habitat for microorganisms in their roots [1]. Often referred to as the soul of the earth, soil is home to trillions of living organisms [2]. Wu (2023) defines 'soil health' as "a state in which the quantities of harmful substances and soil-borne phytopathogens contained in soil do not exceed the threshold of safety to local environments and agroforestry production (sic)". It has been estimated that there are 2.6 $x10^{29}$ bacteria in soil ecosystems; moreover, per gram of soil may contain 10,000 prokaryotic species [3]. However, anthropogenic pollution has significantly increased the levels of pollutants in marine and terrestrial ecosystems [4].

Currently, research on degraded soils is a multidisciplinary and multidimensional field that evaluates both their degradation and recovery processes [5]. Soil biota plays an essential role in the decomposition of organic matter, soil nutrient cycling, and bioturbation and inhibits the transmission of soil diseases [6]. Thus, determining the exposure of soil microbiota to contaminants is crucial for restoring soil degradation [5]. According to the United Nations Environment Program (UNEP), soil health deterioration negatively impacts food security and public health [7]. During 1970 and 2015, approximately 35% of all wetlands, marine coasts, and land were lost due to human activities and natural degradation [8]. Plant roots release organic and inorganic compounds that are involved in respiration, secretion, and nutrient absorption in the soil, forming a plant-soil exchange process [9]. Thus, the rhizosphere is the region of soil influenced by plant roots and contains a diverse set of microorganisms, including fungi, bacteria, algae, and protozoa [9]. For this reason, the microorganisms present in the rhizosphere are of great importance due to their ecological multifunctionality, including their ability to remove pollutants in soil, adapt to the environment, and ameliorate the effects of global warming [8]. In addition, microorganisms can colonize various natural and anthropogenic environments through their resilient metabolism [10]. Plant-microbe interactions affect different physiological processes in plants, regulate plant growth, and maintain ecosystem stability, development, and maintenance [8]. Plants and microorganisms can act as metal hyperaccumulators, sequestering metals from the soil, acting as bioremediators through genes, and detoxifying metal transporters, activities that can occur through plant-microbiota relationships [11]. To understand the process of phytoremediation, it is necessary to understand the development of bacteria in the rhizosphere and the mechanisms of adaptability and growth, even in contaminated soil [1]. Moreover, plant root metabolites provide carbon and energy for microorganisms and regulate the microbial environment, altering microbial forms and communities [8]. Similarly, the study of volatile organic compounds (VOCs) emitted by organisms in soil is in its early stages, but it is necessary to elucidate the metabolomic profile of the soil [12].

The use of "OMICS" tools makes it possible to obtain complete microbiome profiles directly from samples [10]. Advances in omics tools, such as metatranscriptomics, metagenomics, metaproteomics, and metabolomics, allow us to understand the interactions between metabolites and proteins and their relationship with the environment [13]. These tools also facilitate the generation of a large amount of data of different order, such as metabolites, proteins, and genes, that are regulated by distinct signaling pathways interacting with each other [14]. Metagenomics allows the recovery of genetic material from environmental samples, allowing researchers to understand the dynamics of the remediation process in an ecosystem mediated by microorganisms [4]. Furthermore, studying the soil metabolome expands knowledge and understanding of the interaction and functional significance of microorganisms through the interaction of metabolites, which encompasses various biological hierarchies [12]. For example, combining the 16S rRNA unit with the metabolomic analysis of agricultural soil microorganisms allows the evaluation of the toxicity of natural and synthetic triketone-type pesticides used in crop cultivation [15].

This chapter's objective is to understand omics tools for studying soil-microorganism interactions in contaminated soils.

Trash Landfills, Microplastics, and Antibiotics: Soil Pollution

The soil is a complex microecological environment in which microbial activity and root exudate secretion are derived [5]. Biotic and abiotic agents interact ecologically in soil ecosystems to form complex and stable microbial communities [3]. Among the most critical organisms in the soil, bacteria are the most influential group to be used as biotransformation products in soil due to their versatility in metabolism, making them ideal for use in biotransformation processes within the soil [10]. Thus, microorganisms possess several enzymes that are harmful to the contaminants in their environment. These enzymes help to degrade and transform hazardous substances into less dangerous forms [7], including contaminants in landfills [16].

However, the overexposure of microorganisms to contaminants reduces their capacity to sequester contaminants in the soil [17]. Removing contaminants such as heavy metals from soil is necessary to avoid adverse health effects [2]. Because of industrialization and population growth, the levels of substances such as hydrocarbons, heavy metals, and aromatic hydrocarbons have drastically increased [18]. Heavy metals negatively affect economically important plants in

CHAPTER 5

Bioengineering Techniques for Soil Erosion Prevention

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Abstract: This chapter addresses the impact of soil erosion caused by both natural processes and human activity. Soil erosion can create serious environmental damage, such as the reduction of farmable, productive land and increased sedimentation in water. To combat this, bioengineering methods are a way to harness sustainable and environmentally friendly approaches. These methods involve using living vegetation, wood, or other natural materials to manage soil, particularly on slopes, banks of rivers, or retaining walls. Some bioengineering methods discussed are bush mattresses, wattle fences, and jute netting. Bush mattresses involve laying down branches and vegetation across eroding areas to slow down the movement of water and capture sediment. Wattle fences use stakes with woven vegetation to trap soil and prevent erosion. Meanwhile, jute netting is a breathable and biodegradable weave-like fabric that can be laid over the soil to protect it from erosion until vegetation establishes. The effectiveness of these methods relies on careful planning, site-specific conditions, and maintenance of the body of work. While bioengineering methods can support fairly intense workloads and may require a huge number of materials, they offer ecological benefits to prevent soil degradation in the long term. Here, we emphasize that these methods can have a remarkable impact if the appropriate method is selected and routinely maintained. By implementing sustainable practices for soil erosion and environmental management, the goal of sustainable land management can be achieved, contributing to the protection of the environment from the adverse impacts of soil erosion.

Keywords: Bioengineering, Construction methods, Deep rooting, Fascines, Living branches, Natural resources, Prevention, Revegetation, Slope stabilization, Soil erosion, Soil reinforcement, Techniques, Terraces.

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INTRODUCTION

Soil Erosion

The term 'erosion' encompasses different concepts depending on its focus. In general, soil erosion refers to any alteration in the soil or underlying bedrock caused by an external vector. These vectors are also used as classification points to determine the type of erosion being discussed, which is mainly divided into two groups: biotic (caused by living organisms) and abiotic (due to inanimate factors). These groups are subdivided into different types. Biotic vectors include plant organisms (phytogenic erosion), animals (zoogenic erosion), and human activity (anthropogenic erosion), while abiotic factors are divided by the type of phenomenon they generate, whether chemical (corrosion) or physical (mechanical erosion) [1].

Erosion occurs naturally through geomorphic factors such as water, snow, ice, wind, and both plant and animal organisms [2 - 5]. However, climate change and human activity are factors of particular concern as they accelerate soil deterioration. In economically and socially important activities such as agriculture, which cause the elimination of vegetation and soil exposure, it is necessary to carry out adequate planning based on the type of soil to be exploited to ensure that it can be maintained with the least amount of possible alterations in its original qualities. Techniques must be employed either to prevent accelerated deterioration as much as possible or to improve the soil's resilience, *i.e.*, the natural recovery capacity of soils [1, 6 - 9].

If erosion conditions persist, the soil may undergo changes in its properties, such as the strength of the material, infiltration capacity, and plant productivity; these are characteristics that the soil generates in its natural formation processes [10, 11]. For example, the loss of nutrients and organic matter in soils due to erosion are important factors because they can indicate the loss of agricultural productivity, mainly when cultivation practices are not planned. The potential impact of such activities on the soil must be considered, particularly when selecting crops that are less harmful to each specific soil type [6, 12 - 14].

Worldwide, attempts have been made to estimate soil loss due to erosion [15 - 17]. For example, in 2015, the average soil loss in the European Union was estimated at 2.46 mg ha^{-1} yr^{-1} (organic matter in megagrams per hectare per year). However, in some areas of Africa, these values exceed 20 mg ha^{-1} yr^{-1}, and this problem increases every year for foretold reasons [18, 19]. Therefore, soil erosion is a major global concern because of its threat to the food industry and the environmental loss it can cause [20 - 23].

Bioengineering as a Soil Erosion Prevention Strategy

Various strategies have been developed to prevent soil deterioration. Bioengineering uses biological knowledge to generate possible solutions to current problems [24, 25]. In the case of soil erosion, there are techniques to secure unstable slopes and embankments that can be affected by erosion phenomena. These methods make use of whole plants or their parts, rocks, wood structures, and construction materials to build structures that prevent the progressive deterioration of soils and allow their use in a more sustainable and safe manner [26 - 29].

Soil Erosion Prevention Techniques on Slopes and Embankments

Bush Mattress

This type of construction is carried out using live branches to protect and stabilize slopes, reduce the speed of rainwater, control erosion on embankments and slopes, and improve riprap and sediment accumulation to prevent it from being washed away (Fig. **1**).

The construction consists of rectangular sections made with branches. The size of these branches varies depending on the area that needs to be covered. They can be small, 60 cm long by 6 mm wide, or for larger areas, they can be 2 to 3 m long and 2.5 cm in diameter. The branches are tied together to form a cylindrical fascine between 15 and 30 cm long and are used to build a mattress, with the buds facing the same side. The branches are placed on the slope using wooden stakes (can also be live) of 1 meter in length. These stakes are driven into the ground at a depth of 60 - 70 cm and serve as supports to place the strips of branches. Using this structure, it is also possible to plant directly on the fascines by filling them with soil.

This method is effective immediately after placement, as plants with dense rooting are used for its construction. It is important to select plants that can grow adequately according to the type of soil to be protected and can also be used as a base for growing new plants. However, its main disadvantage is the amount of material needed to build it and the occasional maintenance required by the shrubs that are formed.

Installation Process

1. Clean the area and remove any debris from the area to be protected.
2. Dig a trench 10–30 cm deep at the base of the slope.
3. Place cuttings flat on the slope, crisscrossed by pushing the roots against the

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CHAPTER 6

Biofertilizers and Biopesticides: Sustainable Alternatives for Agriculture

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Abstract: The escalating requirements for agricultural production systems to ensure global food security and mitigate environmental degradation necessitate a shift toward more sustainable approaches that reduce adverse effects and increase efficiency in crop productivity and profitability. Historically, the primary method used to achieve these goals has involved the application of chemical fertilizers and pesticides. Nevertheless, the persistent and excessive use of these substances has resulted in contamination, pest resistance, health issues, soil depletion, and diminished microbiota, consequently reducing crop yields. Therefore, the controlled use of pesticides and fertilizers has been recommended, advocating for reduced application amounts and site-specific, targeted administration. One promising solution lies in the use of advanced tools, such as biotechnology and nanotechnology, that have played an important role in agro-technological transformation. Microorganisms, along with biofertilizers and biopesticides, have the potential to enhance agricultural systems and safeguard food security. Nanoparticles are emerging as a cutting-edge technology poised for revolutionizing contemporary agrarian methodologies, balancing crop nutrients, and the supply of pesticides and fertilizers. Diverse nanoparticle-based formulations, including biofertilizers, biopesticides, and nanosized sensors, have been extensively researched for plant health management and soil quality improvement. A profound understanding of the interactions between plants and nanomaterials enhances agricultural techniques by monitoring water quality, improving disease resilience, crop output, pest control, and nutrient absorption. This examination underscores the pivotal

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factors that must be considered in future studies on biofertilizers and biopesticides to enhance productivity and food security.

Keywords: Biofertilizer, Biopesticide, Biological control, Microorganisms, Formulations, Nano-biotechnology, Plant health, Sustainable agriculture.

INTRODUCTION

Environmental sustainability in agriculture refers to the prudent management of natural systems and resources essential for farm operations. Sustainable practices include crop rotation, promoting biodiversity, using cover crops, implementing zero- or reduced-tillage systems, adopting integrated pest management strategies, promoting synergy between livestock and crops, participating in agroforestry techniques, and using precision agricultural methods. The main objective of sustainable agricultural policies is to guarantee environmental sustainability and, at the same time, improve, or at least sustain, agricultural productivity because this represents one of the cornerstones of society and plays a fundamental role in supporting the food of millions of humans globally.

It is estimated that by 2050, the world population will be approximately 9 billion, increasing the demand for land dedicated to agriculture. Currently, approximately 5.5 billion hectares, or 38% of the world's land surface, are allocated to agriculture, of which approximately one-third is allocated to cropland. The global area of cropland per capita decreased continuously during the period from 1961 to 2016: from approximately 0.45 hectares per capita in 1961 to 0.21 hectares per capita in 2016 [1 - 3]. While, the use of fertilizers and pesticides shows an increasing trend, which has allowed, on the one hand, an increase in crop yields, having a positive impact on the producer economies. However, even though global food production has managed to keep pace with population growth, the 2024 report by Food Security Information Network (FSIN) and the Global Network Against Food Crises (UN) on Food Crises [4] reveals that 281.6 million people, equivalent to 21.5% of the population examined, are experiencing high levels of acute food insecurity in 59 countries/territories [5].

On the other hand, the extensive use of fertilizers and pesticides poses significant challenges, including soil contamination and degradation, reduced water oxygen levels, lake eutrophication, loss of species of native plants, animals, and microorganisms, imbalance of soil nutrients, and the accumulation of heavy metals that can be incorporated into the food chain, representing health risks and large amounts of pollution [3, 6, 7]. The above principles are essential for developing environmentally friendly biofertilizers and biopesticides while preserving the benefits of their chemical analogs [8]. Biotechnology plays a fundamental role in developing products based on microorganisms that produce secondary metabolites capable of eliminating pests or diseases in crops and compounds that favor the fixation of essential elements for the nutrition, development, and protection of plant species through symbiotic relationships. Despite the benefits of biotechnology, it is necessary to make responsible use of biofertilizers and biopesticides as improper management can lead to similar negative outcomes as those caused by chemical fertilizers and pesticides. It is essential, therefore, to generate legal frameworks regarding the selection of strains to be used, to increase quality in production, storage, and distribution, and to generate awareness among the population about their benefits, as well as regarding their application. These products are often specific to different soil types and crops, making informed and regulated use crucial for sustainable agricultural practices.

BIOFERTILIZERS

Classification and Mechanism of Action of Biofertilizers

Biofertilizers can be categorized based on various factors, including their mechanism of action and composition. Direct mechanisms include N2 fixers, P solubilizers, and phytohormone producers. In contrast, indirect mechanisms involve substances that facilitate siderophore production, induce systemic resistance, modulate plant stress, generate antibiotics, and stimulate the synthesis of glucanase and chitinase [9]. In terms of composition, biofertilizers are available in solid forms like granules, microgranules, hydratable powders, water-dispersible granules, and shots, as well as in liquid forms such as suspension concentrates, oil-miscible concentrated fluids, sprays, and oil dispersions [10].

The first commercial use of biofertilizers occurred with the introduction of “Nitragin” in 1895. Preparing biofertilizers involves the mass cultivation of microbes under controlled conditions, such as carefully regulating factors such as pH, temperature, and cell count. An appropriate carrier material is essential for ensuring optimal biofertilizer effectiveness. In the future, emphasis should be placed on developing mutant and genetically modified microbes as biofertilizers that offer superior benefits compared with wild-type microbes, thereby providing a sustainable solution to agricultural challenges [11].

Microbial biofertilizers enhance plant growth either by directly acquiring essential resources like growth hormones or indirectly by implementing regulatory mechanisms on various plant pathogens that act as biocontrol agents. The mechanism of action can be categorized into two types. Direct methods involve microorganisms aiding in nitrogen and phosphorus fixation, potassium solubilization, siderophore production, phytohormone modulation, and

CHAPTER 7

Microalgae and Biotechnology: Water Purification and Biomass Production

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Abstract: Water resources suitable for direct human consumption have become increasingly scarce due to the rapid expansion of the global economy and population. Water pollution arises from multiple sources, including municipal, agricultural, and industrial activities, which release a diverse array of toxic pollutants into water bodies daily. These pollutants include heavy metals, pesticides, dyes, pharmaceuticals, and other hazardous substances. Addressing water contamination is, therefore, a critical global challenge that requires sustainable, cost-effective, and efficient solutions. Microalgae offer a promising alternative for wastewater treatment due to their ability to thrive in various wastewater types, low energy consumption, and unique capacity to convert harmful pollutants into valuable compounds. Microalgae-based wastewater treatment systems are particularly attractive because of their low operational costs, minimal environmental impact, and ability to function effectively under a wide range of environmental conditions. Additionally, they can remove a broad spectrum of pollutants through mechanisms like biosorption, bioaccumulation, and biodegradation. The resulting biomass from these processes is of significant interest, as it can be used to produce high-value products such as biofuels, biofertilizers, pharmaceuticals, and food additives, contributing to an integrated and sustainable economic model. This chapter highlights the importance of microalgal wastewater treatment by exploring these three key remediation mechanisms in detail and discusses the potential for microalgae to produce bioenergy and other valuable bioproducts. Furthermore, it addresses the current challenges and future opportunities within the algae-based biotechnology sector, which has recently gained attention for its potential to significantly contribute to environmental sustainability and economic development worldwide.

Keywords: Biomass, Microalgae, Pollutants, Remediation, Wastewater, Water purification.

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INTRODUCTION

Various types of environmental pollution, such as land, air, and water pollution, are responsible for significant environmental imbalances and contribute to global warming. These forms of pollution negatively affect ecosystems, biodiversity, and human health, generating a range of impacts that require urgent attention to mitigate their adverse effects on the planet. Toxic substances include heavy metals, nuclear waste, chemical fertilizers, pesticides, hydrocarbons, and pharmaceutical by-products [1]. While water is abundant in some parts of the world, access to clean water remains a significant challenge in industrially based developing countries. Water pollution is primarily caused by industrial, municipal, and agricultural wastewater, which contains both organic and inorganic pollutants [2].

Various physicochemical and biological methods have been developed to remove or remediate pollutants, including filtration, ion exchange, electrochemical methods, and osmosis. However, most of these methods are neither commercially viable nor environmentally sustainable. Therefore, there is a need for integrated technologies to reduce energy consumption and costs [1].

Currently, biological treatments are preferred over chemical treatments, even though, the latter tend to be faster and can have negative effects on the environment and living organisms. Biological remediation is a low-cost, low-toxicity and a long-term alternative. This process uses microorganisms, including microalgae, fungi, and bacteria, to remove pollutants from the environment [1]. Microalgae, one of the oldest microorganisms, thrive in various hostile environments being particularly useful in wastewater treatment. Thus, microalgae ability to consume or absorb pollutants helps to reduce biological oxygen demand, total suspended solids, pathogenic organisms, nitrogen and phosphorus concentrations in wastewater [2, 3].

Microalgae are versatile organisms because they can continue to grow even under adverse conditions with low nutrient concentrations. In addition, they can adapt to a wide range of environmental applications, making them suitable for various biotechnological applications. This adaptability creates a dual system that enables both pollutant removal and biomass production for commercial purposes. In large-scale biomass production, no additional growth formulations are needed due to their high adaptability. Biomass production is particularly higher in warm regions of the world, where sunlight and favorable temperatures support their growth [4]. Microalgae biomass and its products are used in many industries, such as food, agriculture, fertilizers, pharmaceutical industries, biosurfactants, biofuels, and scientific research.

Importance of Water Purification

Global water consumption has multiplied sixfold in the past 100 years. It continues to increase by 1% annually due to population growth, economic development, and consumption. Climate change has worsened the water quantity situation by increasing the frequency and magnitude of extreme events such as heatwaves, storms, and tempest and unprecedented rainfall [5]. In addition, water is an essential resource for several industries, such as pharmaceuticals, electronics, petrochemicals, agrochemicals, and food, all of which have increasingly affected water quality and availability worldwide [6]. The disposal of water from these industries poses significant risks to both the environment and human health. Wastewater (WW) contains various organic and inorganic compounds that are released into the environment, raising chemical oxygen demand (COD) and biological oxygen demand (BOD). The eutrophication of aquatic environments caused by high concentrations of phosphorus and nitrogen induces the generation of solid waste and unpleasant emissions into the atmosphere [7]. Consequently, the phytoremediation process may be considered as a relevant method to cope with WW. (Fig. **1**).

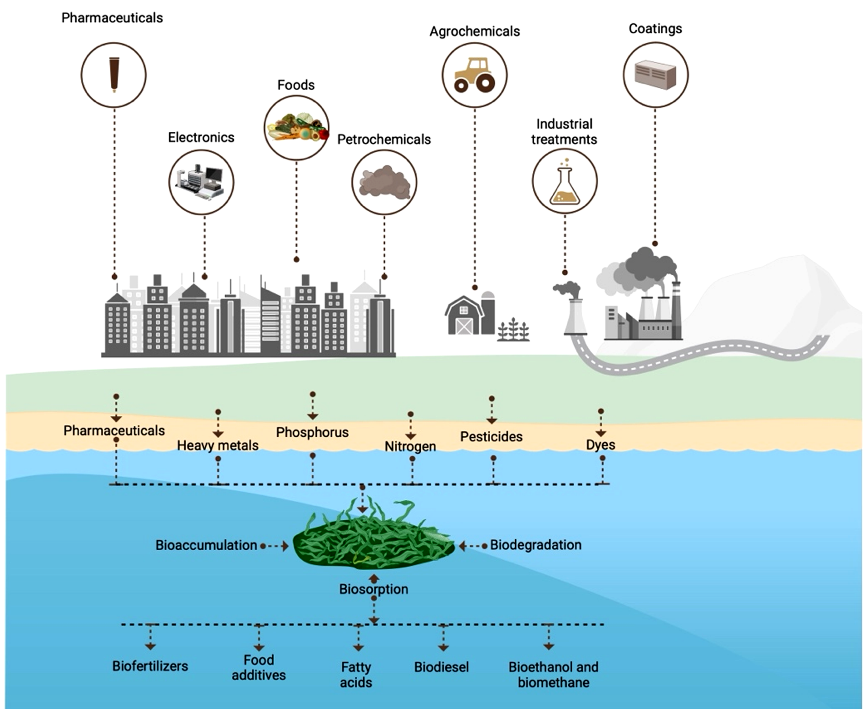

Fig. (1). Treatment of wastewater from different sources and the processes involved in remediation by microalgae. Pathways are associated with microalgae biomass conversion processes. Figure made with Biorender.

CHAPTER 8

Biological Desalination: Biotechnological Alternatives for Freshwater Extraction

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Abstract: Water is essential for life, and accessibility has been a global problem for many years. The estimations provided by the United Nations suggest that the worldwide population will increase to 10.2 billion individuals by the year 2050. As a result, a notable rise in water consumption is projected due to changes in lifestyle and demographic expansion. Numerous innovations have arisen within desalination technology over the past few decades. Thus, the desalination of seawater plays a crucial role in enhancing the accessibility of potable water to populations in need. However, this process requires considerable energy to produce freshwater. Various desalination methods exist for seawater, including thermal and membrane processes. Nevertheless, this practice poses risks to the environment and entails substantial costs. With the swift advancement of industrialization and urbanization on a global scale, there is a rising need for an enhanced clean water supply. Sustainability is becoming a focal point in desalination and wastewater management to meet the increasing global demand for clean water. Given the limited availability of freshwater resources, the sector is progressively considering using recycled water as a crucial approach to guaranteeing sustainable business operations. Biological desalination involves a novel approach that employs diverse salt-tolerant organisms such as bacteria, microalgae, halophyte and halotolerant plants, microbial electrochemical systems, biological membranes, and biopolymers. Compared with conventional desalination techniques, biological tools require less energy and have fewer environmental impacts. Consequently, they are recognized as a more environmentally friendly and sustainable desalination method.

Keywords: Biological desalination, Desalination, Phytodesalination, Seawater desalination, Water desalination.

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Israel Valencia Quiroz (Ed.)

INTRODUCTION

Water scarcity represents an urgent challenge in our time, impacting around four billion people who face severe water deficits for at least a month a year [1]. Numerous public health emergencies are presently being impacted by water sources, such as floods, droughts, and waterborne illnesses. This problem is intensified by climate change, amplifying floods and droughts, altering precipitation patterns, changing water sources, hastening the melting of glaciers, and rising sea levels. Access to clean water is crucial for human well-being, industry, agriculture, and energy generation, making water a significant humanitarian concern [2 - 5]. Despite the vast water resources on Earth's surface, more than 99% are currently inaccessible for human consumption. Over 97% of Earth's water exists as saltwater in oceans, bays, seas, and saline aquifers, acting as significant reservoirs. Various assessments showed that the usable freshwater supply was approximately 0.7% [6 - 8].

Projections from the United Nations indicate that the global population will increase from 9.4–10.2 billion by 2050 [9, 10]. Consequently, a significant increase in water consumption is anticipated due to lifestyle shifts and population growth. In addition, projections from the United Nations indicated that by 2025, around 2.7 billion people could face water scarcity challenges. The study also forecasts that between 2.7 and 3.2 billion individuals will live under severe water scarcity conditions by 2050 [11]. Although there are adequate freshwater reserves globally, the primary obstacle is the need for additional infrastructure to produce and distribute potable water in specific regions [12]. Among the many difficulties in the quest to produce high-quality drinking water, seawater desalination has been recognized as a crucial step in advancing the development of sustainable freshwater sources [1, 7].

Desalination is a technological procedure for eliminating salts and dissolved impurities from brackish or saltwater [13], with seawater commonly serving as the primary source. Desalination is a widely used method to address water scarcity in some areas of the world where brackish or saline water is present [14]. The estimated value of the global water desalination market is USD 17.47 billion in 2024, with a projected increase of USD 31.32 billion by 2031. Concerning the technological aspects, reverse osmosis (RO) is projected to have a market share of 36.7% by 2024 [15].

Significant advances are currently being made in desalination technologies to mitigate water scarcity. Various membrane distillation methodologies are gaining traction owing to their ability to desalinate seawater with significantly lower energy requirements than conventional thermal distillation approaches. For instance, combining solar thermal desalination facilities with membrane distillation has proven highly efficient in dry coastal areas. These facilities have been established in countries such as Spain, Australia, and Mexico to supply clean drinking water to local populations [15].

Ensuring global access to safe water is crucial, and climate change requires energy efficiency, minimal greenhouse gas emissions, sustainable water consumption, and pollution reduction. Biological desalination is a novel approach that exploits the absorption and adsorption of salts by diverse salt-tolerant organisms [16]. A wide array of different species of organisms, including plants, microalgae, and bacteria, have undergone adaptations to thrive in environments characterized by fluctuating levels of salinity, evolving intricate mechanisms aimed at expelling excess intracellular NaCl. This phenomenon has sparked the interest of the scientific community, prompting a thorough investigation into the feasibility of harnessing biological processes for seawater desalination [17].

Biodesalination is emerging as a cutting-edge technology designed for the targeted extraction of Na^+ and Cl^- from saline water bodies, leveraging the specialized capabilities of organisms with remarkably minimal energy expenditure. Within this realm, the scope includes microbial desalination cells, which facilitate the simultaneous desalination of water resources while concurrently executing wastewater treatment procedures, thereby combining two essential processes [17, 18]. Bacteria serve as bioelectricity producers that supply the necessary energy for desalination in microbial desalination cells. Additionally, numerous species of algal cells can thrive in high salt concentrations, absorbing and storing them internally, thus enabling their direct application in seawater desalination without prior processing. Biopolymers play a role in seawater treatment by enhancing water evaporation in solar steam generators [18].

The direct use of living organisms in the desalination of water resources presents a promising approach for further exploration. Nevertheless, the advancement of these innovative technologies and their eventual practical implementation hinge on the precise selection of living organisms that are most suitable for desalinating seawater [17]. In contrast to traditional desalination methods, biological desalination systems exhibit reduced energy requirements, a limited environmental footprint, and fewer engineering intricacies. As a result, it has been acknowledged as a more sustainable and environmentally friendly approach [16]. This chapter presents a concise overview of existing and emerging advancements in water desalination biotechnology, particularly focusing on the attainment of biological states in the desalination process.

CHAPTER 9

Biological Treatment of Wastewater: Use of Microorganisms for Purification

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Abstract: Biological treatment of wastewater leverages the power of microorganisms to purify domestic and industrial effluents. Key processes include the conversion of carbon, organic, and nitrogen compounds, sulfate reduction, denitrification, and the fermentation of methane and volatile fatty acids. These microbial activities clean the water but also produce valuable biosolids, biogases, and protein compounds that can be recovered and reused. Microorganisms such as bacteria, fungi, algae, and archaea are central to these processes. They thrive in diverse nutrient and physicochemical conditions, enabling the degradation and remodeling of pollutants. The advantages of biological treatment span technical, economic, and environmental aspects, offering a sustainable solution to manage a wide range of organic contaminants. Wastewater treatment involves a sequence of physical, chemical, and biological steps to effectively separate and remove impurities. The importance of this treatment is universally recognized, particularly for water destined for human consumption. Rapid industrial growth and population increases have intensified the demand for clean water, yet a significant portion of available resources is saline or contaminated. Pollution from organic and inorganic substances further complicates conventional treatment methods, making biological processes crucial for efficient contaminant removal. Innovative biotechnological approaches inspired by natural microbial processes have expanded the potential for environmental decontamination. These methods offer significant benefits for human health, agriculture, energy, and overall environmental protection. Understanding and harnessing the biological capacities of microorganisms is key to developing more effective and sustainable wastewater treatment strategies.

Keywords: Biosolids, Biological purification, Biodegradation, Denitrification, Environmental decontamination, Industrial effluents, Microorganisms, Methane fermentation, Sustainable water management, Wastewater treatment.

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INTRODUCTION

The present chapter aims to discuss the methodological aspects associated with the treatment of domestic and industrial wastewater using biological methods. It highlights the microbial group and metabolic pathways employed in the process while also discussing the possibility of recovering by-products of biotechnology interest, in addition to the monitoring and control of these treatment systems for the mitigation of environmental and public health [1, 2].

In biological processes, the microorganisms utilized for the purification of water carry out the processes of conversion of carbon, organic, and nitrogen compounds, sulfate reduction, denitrification, and methane and volatile fatty acid fermentations. They also capture some heavy metals and precipitate phosphates. These modifications lead to the formation of new biosolids, biogases, and cellular and extracellular protein compounds that can be recovered for specialized synthesis, while the purification products received are removed from the environment and can be recycled [3, 4].

In addition to the methods previously mentioned, biological treatment is another existing method used for the purification of water, presenting various advantages from technical, economic, and environmental points of view in the attenuation of a wide range of organic-contaminated compounds present in water. The use of microorganisms to degrade and/or remodel pollutants is a fundamental component for the maintenance of soil and water quality in the natural environment and is a significant parameter in domestic, urban, and industrial wastewater treatment systems. Differences in the diversity of nutrients (concentrations and types of carbon sources, nitrogen, phosphorus, vitamins, mineral ions, and other essential nutrients), cell concentrations, and physicochemical conditions (oxygen, pH, temperature, chemical toxicity, and other related factors) have led to the identification of various microbial groups and the contrasting structures used for strict or facultative responses to changes in physicochemical conditions [5, 6].

Treatment and purification of waters contaminated by some substances (industrial discharges and urban effluents) are usually carried out using a treatment sequence consisting of a series of steps, each one of which employs physical, chemical, or biological processes to accomplish the separation and complete or partial removal of inorganic and organic impurities. For example, physical processes include sedimentation and flotation, while chemical processes encompass precipitation, coagulation, maceration, adsorption, ion exchange, and oxidation/reduction [7, 8].

The importance of treating and purifying water, especially water intended for human consumption, is universally recognized. In the absence of appropriate measures, the drainage of domestic and industrial effluents readily leads to a significant environmental problem. Rapid growth in the world's population and in industry over the last few decades has contributed to the increasing demand for water. However, a significant percentage of the resources available to mankind consists of saline or contaminated water, whose physical and chemical characteristics render them unsuitable for various intended uses. Furthermore, pollution of natural water sources with organic and inorganic substances makes conventional methods of water treatment, such as coagulation and maceration, and disinfection with chlorine or ozone addition, inefficient for minimizing the risks of human contamination during the water cycle since these compounds have carcinogenic effects. The efficient removal of contaminants from water is important not only to protect human health but also for use in agriculture, energy, industry, and general environmental protection. The development of water and wastewater treatment methods, particularly those inspired by life's attitudes toward protein functions in the enzyme protein system of living beings, has provided numerous possibilities for use in environmental decontamination [9, 10].

Types of Wastewater

Municipal wastewater comprises both domestic sewage and industrial wastewater.

Industrial wastewater originates from producing, commercial, or storage sites. The composition of water from industrial sources depends on the manufacturing processes involved and may contain a toxic component and unusually high concentrations for some substances.

Domestic wastewater generated from private houses, schools, businesses, and public places is known as sewage.

Water serves various purposes, including for drinking, washing, food preparation, recreation, or the manufacturing of goods. Wastewater is water that has been used and is contaminated with organic and inorganic materials because of washing, food preparation, recreation, supplying toilet water, or other uses. Sources of wastewater include agricultural, industrial, commercial, and human waste. Wastewater has different degrees of contamination according to its source [11, 12].

Biological Treatment Methods

In the activated sludge treatment method, treatment is conducted in a treatment machine like that depicted in Fig. (**1**). Wastewater introduced here is mixed with activated sludge in a tank, where purification is performed. Air is then blown into this tank to activate the sand. The dissolving oxygen is consumed in the treatment process, and so it must be supplemented by blowing air into the tank to maintain

CHAPTER 10

Bioremediation of Contaminated Waters: Strategies and Success Cases

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Abstract: Bioremediation of contaminated waters is an essential strategy to address pollution from various sources, such as industry, agriculture, and urban activities. This approach employs biological agents, including plants, microorganisms, and their enzymes, to detoxify and remove pollutants from aquatic environments. Bioaugmentation, involving the introduction of specialized cleanup microorganisms, is a significant technique, often requiring genetic engineering and extensive testing to ensure the microorganisms can survive and perform effectively in the target environment. Phytoremediation, where plants are used to absorb and degrade contaminants, is another crucial strategy. Contaminants affecting water bodies include oil, heavy metals, persistent organic pollutants (POPs), and agricultural chemicals, originating from point sources like factories and wastewater treatment plants, as well as non-point sources such as urban runoff and atmospheric deposition. The negative impacts of these contaminants range from aesthetic concerns to severe threats to human health and ecosystems. Bioremediation harnesses the natural detoxifying abilities of microorganisms and plants. Bacteria and fungi play a crucial role in transforming and detoxifying a broad spectrum of pollutants. Techniques like biostimulation enhance the activity of native microorganisms by adding nutrients or biosurfactants, facilitating the degradation of hydrocarbons and other contaminants. Phytoremediation utilizes plants to extract, stabilize, and degrade pollutants, providing a cost-effective and environmentally friendly solution. Success cases of bioremediation, such as the treatment of the Exxon Valdez oil spill and the recovery of Lake Washington from sewage pollution, demonstrate the effectiveness of these strategies. Challenges remain, including optimizing treatment efficiency and addressing emerging contaminants. However, ongoing research and technological advancements continue to improve the sustainability and applicability of bioremediation for large-scale environmental cleanup efforts.

Keywords: Bioremediation, Bioaugmentation, Detoxification, Environmental cleanup, Heavy metals, Microorganisms, Pollutants, Phytoremediation, Persistent organic pollutants, Water contamination.

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INTRODUCTION

Bioaugmentation usually requires large-scale propagation or the preparation of specialized cleanup microorganisms that have been genetically engineered. This process often involves significant investment and careful regulation. When considering the use of naturally occurring microorganisms for bioaugmentation purposes, it is important to perform extensive testing to determine the ability of the candidate microorganisms to survive in the receiving environment and perform the desired pollutant degradation processes. Reliable candidates for bioaugmentation can often be found or constructed by specialized methods, such as rational design or directed evolution. The process in which plants act in the reclamation of nutrients or pollutant levels in contaminated water or sediments through their natural growth and nutrient uptake is generally regarded as phytoextraction or phytoremediation (Fig. **1**) [1, 2].

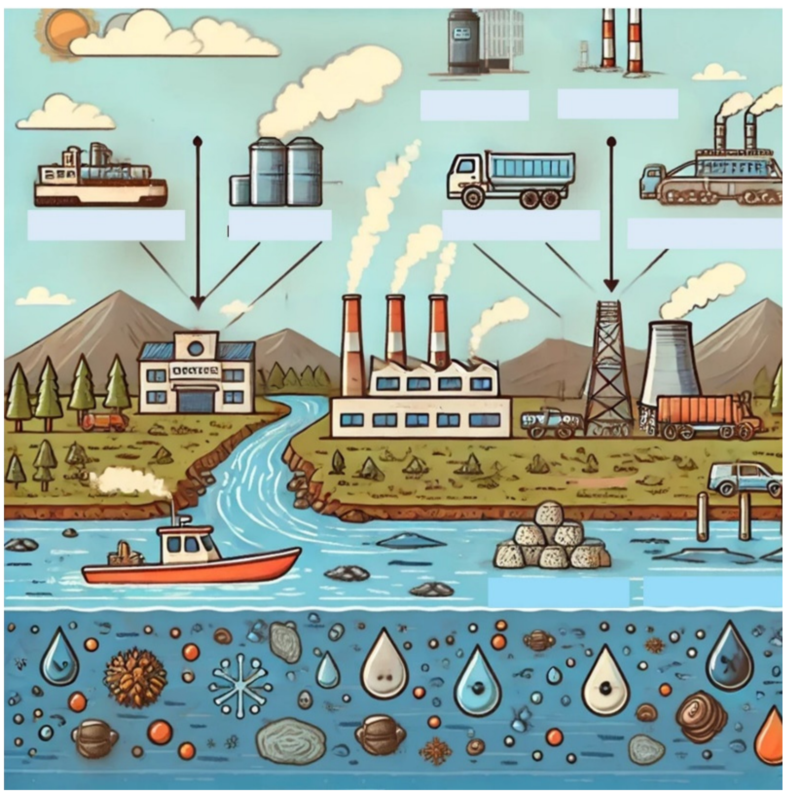

Fig. (1). Main sources and types of contaminants affecting water bodies. Contaminants include products from human activities such as oil, heavy metals, POPs, detergents, and agricultural chemicals. The figure highlights both point sources, such as factories and wastewater treatment plants, and non-point sources, including agriculture and urban runoff, that contribute to the pollution of rivers, lakes, and seas. Figure made with DALL-E.

Despite all the efforts, water bodies continue to be affected by different sources of pollution. Industry, agriculture, services, and tourist activities are frequently responsible for water contamination, making the restoration of affected aquatic ecosystems a pressing priority. For that, one of the available technologies is bioremediation, which relies on the use of biological agents such as plants, microorganisms, or their enzymes to clean up pollution. When this biological approach is specifically facilitated by using microorganisms, it is often called "bioaugmentation" [3].

Sources and Types of Contaminants

The contamination of rivers, lakes, and sea waters with different types of chemicals is a well-known environmental problem. In general, the main contaminants in these waters are products from human activities such as oil, heavy metals, radioactive elements, detergents, agricultural chemicals (pesticides, herbicides, and fertilizers), BOD, and VOCs [4]. The effects caused by these contaminants can range from slight aesthetic problems to severe harm to human health and the environment. The sources of these aquatic pollutants are varied, and the contamination can occur from point sources (such as factories, refineries, sewage treatment plants, and vessels) as well as from non-point sources (agriculture, urban runoff, atmospheric deposition, and natural earth leaching) [5].

Numerous hydrocarbon pollutants are discharged into aquatic environments each year. These pollutants mainly originate from oil spills (accidental release of oil-related products into the environment) and discharges of oil from vessels, as well as from illegal land-based disposal of oil. POPs are another major group of contaminants in water. These chemicals are heavily used in manufacturing processes, and their accidental release or improper disposal can cause severe contamination. In addition, the heavy metals Hg, Cd, Pb, and As are among the most toxic contaminants in the aquatic environment due to their high toxicity and long-term effects on biota and human health. Although the concentrations of these toxic elements in the aquatic environment are generally very low, they tend to bioaccumulate within the food chain. As a result of the harmful accumulation of these substances in the marine environment, more and more restrictive measures are being implemented to protect marine ecosystems and human health [6 - 8].

Bioremediation: an Overview

Bioremediation is an innovative use of living (micro)organisms to clean up environmental pollution. These innocent, invisible helpers form a natural army that can detoxify and eliminate a wide range of environmental contaminants. It has long been appreciated that microorganisms such as bacteria and fungi have the unique ability to transform and detoxify a broad spectrum of organic

CHAPTER 11

Luminescent (Bio)sensors for Pesticide Detection: An Innovative Tool for Water Monitoring

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Abstract: This chapter provides an overview of new fluorescent (bio)sensors designed for commonly used pesticides with a focus on molecular design and applications in real samples. Organophosphate and organochlorine pesticides have many applications in silviculture, public health, pest control, the food industry, and agriculture. Chronic exposure and acute contact with these agrochemicals result in toxic levels in animals, plants, humans, and ecosystems in general. Due to the toxicological, biochemical, and environmental effects of the accumulation of toxic agrochemicals in soil, food, and natural water resources, there is an imperative need to achieve analytical tools capable of working with real samples. In the last decade, research has explored the structural, reactivity, and detection aspects of sensory systems, ranging from the small organic molecules to more complex networks coordinated to metal centers involving transition metal or lanthanide ions, as well as biological nano-systems such as biosensors. The primary goal of (bio)sensors is to develop affordable, easy-to-process, efficient, economical, and stable methods for the accurate and reliable quantification of pesticides in real samples by simple visual detection. The challenge to achieve this goal starts with the (bio)synthesis strategies and their functionality in aqueous media to get efficient environmental monitoring. This chapter describes the relevant features for the development of (bio)sensors based on metal-free organic luminophores, luminescent metal-complexes, metal complexes, metal-organic frameworks, and fluorescent biosensors containing enzymes. These (bio)sensors can be used to quantitatively detect common pesticides and agrochemicals in soil, fruits, vegetables, and water. Key features include molecular strategies, luminescence detection mechanisms, scientific methodology, sensitivity, and analytical precision.

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Keywords: Acetylcholinesterase, azinphos-methyl, Biosensors, Chemosensors, Chemodetection, Detection, Enzymatic biosensor, Fluorescence, Glyphosate, Metal complexes, Malathion, MOF, Organic luminophores, Organophosphates, Organochlorines, Parathion-methyl, Pesticides, Paraoxon, Quantification, Soil, Water.

INTRODUCTION

Efficient monitoring of water quality is a scientific topic of global interest. It is very challenging due to the enormous increase in water consumption in agriculture, the food industry, the textile industry, and mining, among other human activities. The monitoring includes the quantitative detection of pollutant chemical species such as pesticides to know if a water source is suitable and safe for human and animal consumption, as well as for the aquatic ecosystem in the world [1]. Pesticide monitoring water is essential to evaluate the efficacy of mitigation measures aimed at curbing pollution [2]. The development of novel analytical methodologies for selective fast sensing of target pesticides capable of operating in aqueous phase or real samples is an active and relevant field of modern analytical chemistry that impacts biological chemistry and environmental sciences [3].

In recent decades, the production of food with longer shelf life and supply chains has been considered key and challenging objectives due to the growing demand of the world's population. In this context, the growing of vegetables, crops, and fruits has been challenging without the use of agrochemicals. It is well known that pesticides commonly enter groundwater bodies, rivers, lakes, and seas through surface runoff, often from an agricultural field, industrial activities, or neighborhoods where they are applied, causing irreversible damage and posing significant health risks to humans [4]. Considering the health damage that pesticides cause in living organisms, it is urgent to develop analytical tools that detect these chemicals in food and irrigation water [5].

To date, very few analytical methodologies can detect agrochemicals, such as herbicides or pesticides, with considerable sensitivity in aqueous media. Instrumental techniques such as chromatographic-mass spectrometry and some spectroscopies (*e.g.*, Raman) are difficult to perform as they often require pre-treatment of the samples and specialized labs [6, 7]. Among the available analytical techniques, luminescence stands out due to simpler detection techniques, high signal to noise ratio, real-time responses, and efficiency in quantifying harmful chemicals such as pesticides [8].

This chapter highlights recent examples of fluorescent sensors that efficiently detect pesticides and herbicides in water and real samples, such as fruits and vegetables. The selected examples are based on organic fluorophores, metal complexes, metal-organic frameworks, and biosensors involving enzymes.

In all cases, the optical sensing of specific agrochemicals is achieved by monitoring the changes in their photoluminescence features.

The examples presented in this book chapter focus on the fluorescent detection of the most widely used pesticides worldwide based on organophosphate and organochlorine molecules. Fig. (**1**) compiles the chemical structure of the pesticides addressed herein.

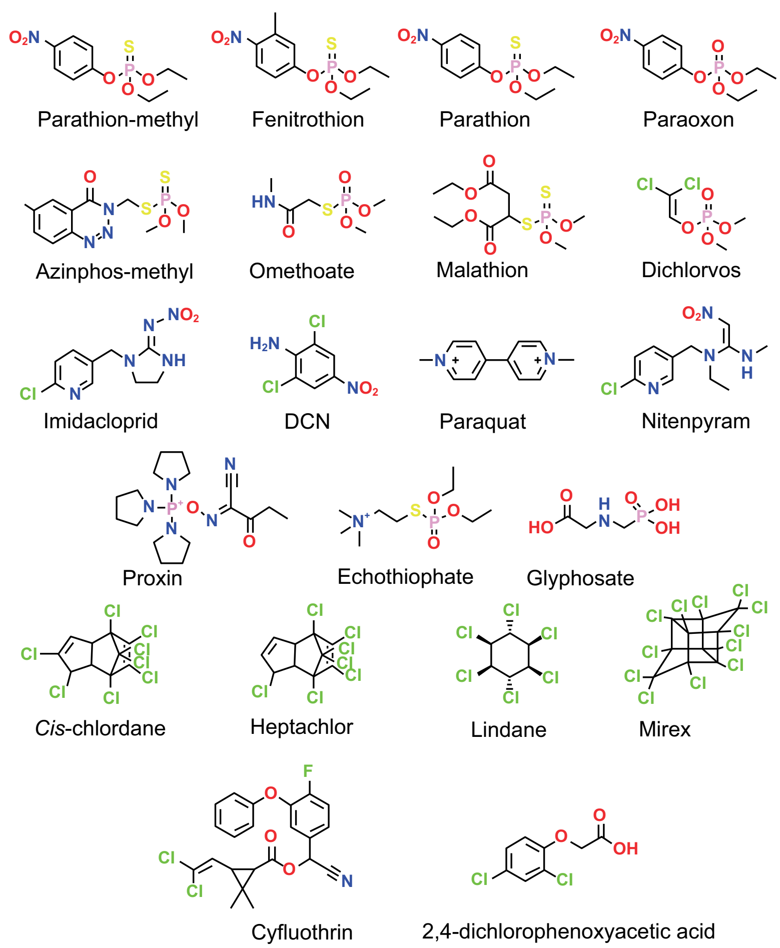

Fig. (1). Chemical structure of pesticides addressed in this work.

CHAPTER 12

Nanotechnology for Water and Soil Conservation

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Abstract: One of the great challenges of our time is to maintain and improve the quality of water, air, and soil so that the Earth can continue to support life. Human activity over the last two centuries has released large quantities of pollutants into the environment, damaging ecosystems as a result of the economic activities, including agriculture, that have enabled human development. These challenges include mitigating the effects of climate change, the unsustainable use of natural resources, and the excessive use of chemicals. Water scarcity is a global threat to life. Nanotechnology offers the potential to change agriculture and water management. Nanotechnology is the science of manipulating matter at the nanoscale, *i.e.*, the scale of 10^{-9} meters, by controlling its shape and size, which can be applied to the design, characterization, fabrication, and application of nanometric-sized structures, devices, and systems. This versatility spans from medicine to agriculture, offering efficient, flexible, and multifunctional processes. Nanoparticles can penetrate microscopic spaces, and their application in environmental sciences includes restoring soil quality and fertility and improving fertilizer efficiency. They, therefore, have great potential for sustainable agriculture. Nanomaterials can be used for water treatment because their physicochemical properties are entirely different from those of conventional-size materials. These properties enhance their efficiency and make methods such as adsorption/oxidation more powerful. The application of nanotechnology is expected to provide an efficient and economical means of supplying drinking water and removing contaminants from soils. This chapter discusses how nanotechnology can be used in water and soil conservation.

Keywords: Nanoparticles, Pollutants, Purification, Remediation, Soil quality, Water.

INTRODUCTION

Nanotechnology is the science of creating structures of a required shape at a scale of 10^{-9} meters by manipulating the physical and chemical properties of a substance at molecular levels [1 - 5].

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Nanotechnology can be applied to design materials and equipment of minute size, conferring them greater reactivity contact surface. Nanomaterials have high reactivity, functionalization, a large specific surface area, and size-dependent properties [1 - 6].

Quantic effects and the increase in relative surface area are the two main characteristics of nanomaterials. Other important characteristics are a) morphology, b) appearance/size ratio, c) hydrophobicity, d) solubility/toxic species release ratio, d) surface area/rugosity ratio, e) induction of reactive species synthesis, f) structure/composition, g) binding sites, and h) dispersion/aggregation rate (Z-potential) [4, 7]. The physical properties of a redox process are important, but at the nanoparticle level, they are even more important [8, 9].

The adaptation of diverse practical methodologies for the synthesis of nanoparticles by modulating their shapes, sizes, and chemical compositions has yielded a multitude of multidimensional structures (1-D, 2-D, and 3-D), enabling their interaction with organic molecules and eliciting combined behaviours (Fig. **1**). The two principal approaches to nanoparticle synthesis are the top-down and bottom-up approaches [10, 11].

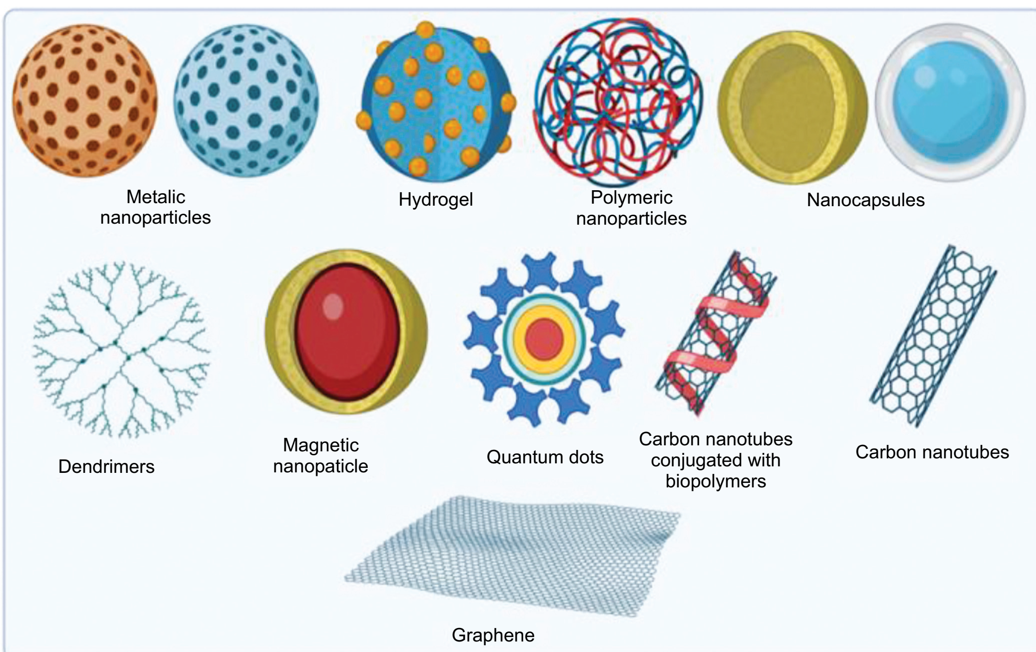

Fig. (1). Different nanoparticle types employed in water and soil conservation.

Nanotechnology processes are highly efficient, flexible, and multifunctional; they are a suitable option for retrofitting conventional infrastructures and developing high-performance, low-cost treatment solutions that are not dependent on large infrastructures [12, 13]. It can improve water purification processes and even reduce environmental problems. However, further research is needed to ensure it does not lead to additional pollution problems [5]. Nanotechnology has the potential to significantly change agriculture and water management [13 - 16].

This new technology can address long-standing issues such as hazardous waste landfills and is ideal for *in situ* applications [5, 14, 17]. Nanoparticles can penetrate small areas in the subsurface and remain suspended in groundwater due to their tiny size. They may be coated with different materials, such as biopolymers. Their size and coating allow them to travel farther and achieve a more homogeneous distribution. However, in practice, nanomaterials do not travel far from their point of injection [8, 18].

Applications of nanotechnology in environmental sciences include using nanoclays and zeolites to restore soil quality and fertility and improve the effectiveness of fertilizers. Another use is the development of nanopolymer-coated smart seeds programmed to germinate under favorable conditions [6, 17, 19, 20]. Crops are classified according to their nutrient needs, so the use of nanobiosensors with satellite systems allows a more precise supply of nutrients than with current methods [21]. This also enables the more efficient application of nanoherbicides and nanofertilizers, helping to avoid or reduce contamination issues [19]. Therefore, the application of nanotechnology in sustainable agriculture has great potential, especially in developing countries [22].

Nanotechnological methods have proven effective and are widely used in soil remediation. The recent use of nanoparticles for processes such as adsorption, redox reactions, precipitation, and co-precipitation processes has successfully removed contaminants from soil due to their enormous specific surface area [4, 17].

The treatment of water with nanomaterials is beneficial because the physicochemical properties of these materials are entirely different from those of conventional sizes [23]. The use of nanomaterials in conventional water treatment improves their efficiency. Methods such as adsorption, oxidation, and separation have been developed using nanoadsorbents, nanocatalysts, and bioactive nanoparticles, which are more effective due to their size and larger surface area/volume ratio [15, 16, 24].

Nanoparticles are easily added and dispersed in reactors to treat soils, sediments, and solid wastes. Nanoparticles can be immobilized in solid matrices, such as

CHAPTER 13

Conservation and Reuse of Water in Agriculture: Biotechnological Techniques for Efficient Use

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Abstract: Agricultural water conservation involves implementing sustainable practices that reduce water loss and optimize water use efficiency. Techniques such as drip irrigation, precision agriculture, and mulching play a crucial role in minimizing water wastage. Additionally, treating water for reuse and utilizing low-quality water for irrigation are essential strategies to ensure safe and effective water use. Proper soil management enhances the absorption of wastewater, preventing salt accumulation that could harm crops. Traditional methods like plant breeding and optimizing planting times complement modern biotechnological approaches, such as genetic modifications, to improve water efficiency. Agriculture consumes the majority of the world's water resources, highlighting the need for efficient water management to prevent contamination and ensure sustainability. Water scarcity poses significant challenges to food security, particularly in regions reliant on rain-fed agriculture. To address these challenges, strategies such as developing drought-tolerant crop varieties, integrated water resource management, and the reuse of treated wastewater are being employed. Emerging biotechnological techniques, including the use of transgenic plants and innovative water treatment technologies, offer promising solutions for water conservation in agriculture. Case studies demonstrate successful applications of hydroponics, low-pressure irrigation systems, and the integration of biotechnological solutions in real-world settings. Future directions emphasize the importance of continued research and innovation in biotechnology to enhance water use efficiency, promote sustainable agricultural practices, and address the global water scarcity crisis. By adopting these advanced techniques, the agricultural sector can significantly contribute to the conservation and efficient use of water resources, ensuring long-term food security and environmental sustainability.

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Keywords: Agricultural water conservation, Biotechnological techniques, Drought-tolerant crops, Drip irrigation, Genetic modifications, Precision agriculture, Soil management, Sustainable agriculture, Water reuse, Water efficiency.

INTRODUCTION

The term "agricultural water conservation" refers to the beneficial use of water to promote sustainable agriculture by reducing water loss through evaporation from the soil and providing water to crops at optimal times for growth while considering the surrounding environment. Water conservation measures can be implemented at all stages of crop production, including soil preparation and irrigation practices. Implementing water-saving techniques such as drip irrigation, precision agriculture, and mulching can greatly reduce water wastage. Additionally, the use of water treatment techniques is crucial to enable water reuse or the utilization of low-quality water for irrigation purposes. Treating water ensures that it is safe for plant uptake while minimizing any potential harm to the environment. Proper soil management is also essential for agricultural water conservation. Adequate preparation of the soil allows for efficient absorption of wastewater or other low-quality water, preventing excessive accumulation of salts that could potentially damage crops and hinder productivity. By implementing comprehensive water conservation strategies and adopting sustainable farming practices, farmers can mitigate the impact of water scarcity and enhance the long-term viability of agricultural systems [1, 2] (Fig. **1**).

The growing scarcity of water for agriculture has driven the search for techniques to reduce water use by increasing efficiency in crop production. This chapter discusses several traditional and modern biotechnological techniques, especially those involving genetic modifications. Traditional methods include plant breeding and selection, optimizing planting times, using organic amendments, and integrated water management. Modern techniques involve collaborative action with companies producing seeds and agrochemicals [3, 4].

Importance of Water in Agriculture

Globally, approximately 70% of water resources are used for agriculture, 16% for industry, and 14% for domestic purposes. However, these proportions vary across different regions of the world. Agriculture consumes most of the water available for human use, underscoring its great social importance in water resource management. Efforts to increase water use efficiency and reduce percolation are crucial in minimizing contamination of aquifers and surface water. It is estimated that about 40% of the world's irrigation water is used on crops that are highly sensitive to water shortages, resulting in decreased yields (Fig. **2**) [5, 6].

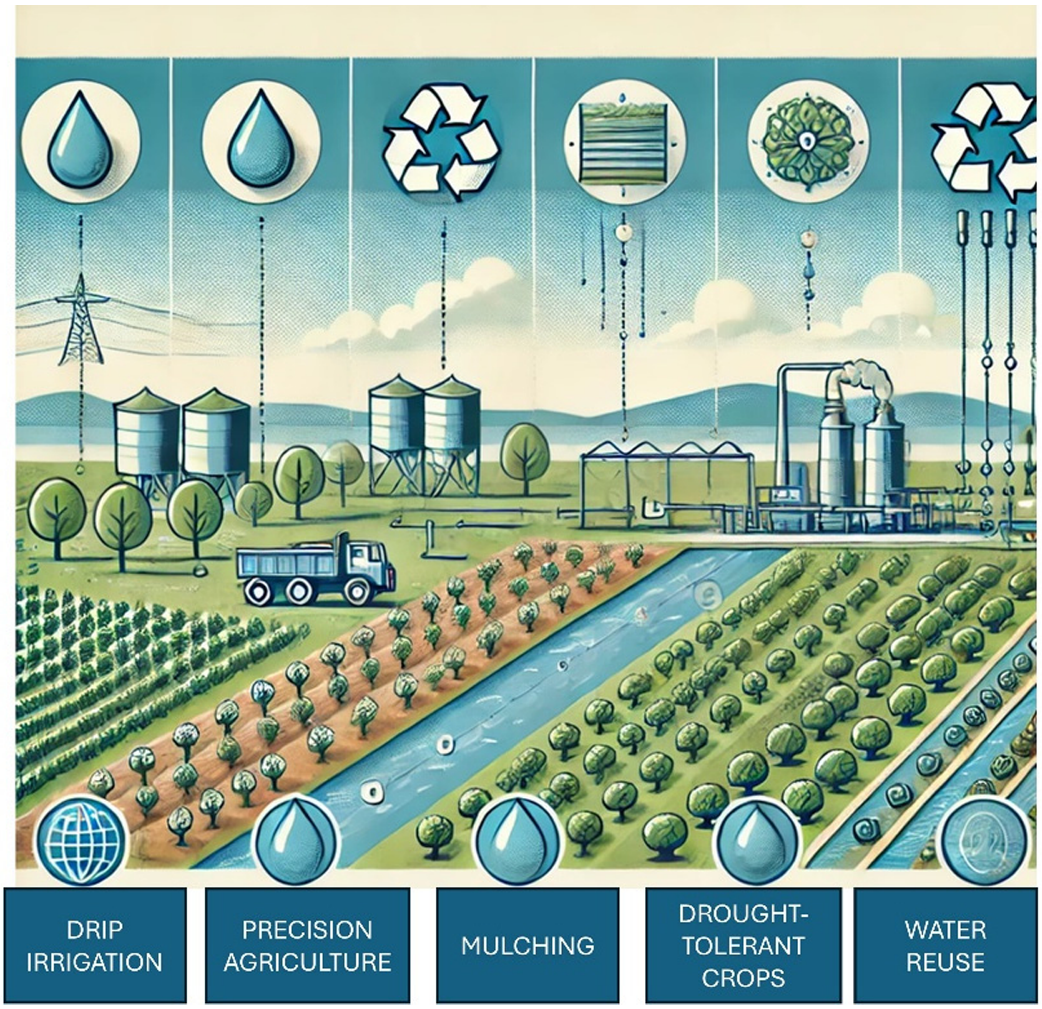

Fig. (1). Various water conservation techniques employed in agriculture. The figure illustrates methods such as drip irrigation, precision agriculture, mulching, water reuse, and drought-tolerant crops. These strategies help reduce water waste and enhance sustainable agricultural practices. Figure made with DALL-E.

Fulfilling the right to an adequate standard of living includes access to a sufficient amount of good-quality water. Nearly 70% of the world's poor people live in rural areas and depend on agriculture for their livelihood. However, most poor farmers cannot ensure stable food production due to inadequate, unreliable, or unaffordable water supplies in their rain-fed or irrigated agricultural systems. Indeed, high risks of food insecurity due to water shortages are significant for both rain-fed and irrigated agriculture. It is known that higher levels of investment are needed to reduce these risks linked to water shortages in rain-fed areas compared to investment needed in areas with supplementary irrigation. In

CHAPTER 14

Ethical and Social Challenges of Environmental Biotechnology

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Abstract: Environmental biotechnology offers the potential to develop and commercialize clean biological processes to restore, preserve, and improve the environment. However, these advancements also bring ethical and social challenges that require careful consideration. A primary ethical issue is the equitable distribution of the benefits of biotechnological processes among affected communities. It is essential to respect the autonomy of individuals and communities who oppose these technologies. Dialogue and democratic procedures are essential for addressing concerns and ensuring public participation in decision-making. Environmental biotechnology is subject to public scrutiny and criticism, particularly from influential interest groups concerned about the effects of these technologies on the environment and human health. Ethical considerations include the equitable distribution of benefits, public participation, and informed consent. The implementation of these principles depends on the legal frameworks and governmental support in different countries. The social implications of environmental biotechnology are significant. Public debate is often heated, with concerns arising from fears and uncertainties about new technologies. The bioprocessing industry must address these concerns through transparency and by involving communities in project decision-making. Traditional practices may also be affected, raising social concerns and potentially eroding cultural values. Regulatory frameworks and policies play a crucial role in managing the risks associated with environmental biotechnology. International agreements and conventions aim to establish common principles and rules to ensure safe and ethical applications of biotechnology. Case studies and examples, such as the use of biochar in soil amendment, highlight both the potential benefits and challenges of these technologies.

Keywords: Bioremediation, Bioethics, Community concern, Environmental biotechnology, Ethical considerations, Public participation, Regulatory frameworks, Sustainable practices, Social challenges, Technology implementation.

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INTRODUCTION

Environmental biotechnology encompasses the application of biological processes and organisms to address and remediate environmental challenges. This multidisciplinary field combines principles from biology, chemistry, and engineering to develop sustainable solutions for pollution control, waste management, and resource conservation. By leveraging natural processes, environmental biotechnology aims to restore, preserve, and enhance the environment. The scope of this field is broad, including bioremediation of contaminated sites, the development of eco-friendly industrial processes, and the enhancement of agricultural practices through bio-based technologies. Ethical considerations play a crucial role in this domain, as the implementation of biotechnological solutions must be guided by principles of fairness, public participation, and respect for community autonomy. Addressing the social challenges and ensuring equitable distribution of benefits is essential for gaining public trust and fostering acceptance of these technologies. This chapter delves into the ethical and social dimensions of environmental biotechnology, highlighting the importance of ethical principles, regulatory frameworks, and community engagement in the successful implementation of biotechnological innovations.

Ethical Considerations in Environmental Biotechnology

If the installation of a clean process to ensure the decontamination of a nearby degraded ecosystem generates concern among the local or nearby inhabitants, the company should consider the reasons for this opposition and begin a dialogue with the affected individuals to address their concerns. In this case, the ethical principle recommended is to respect the autonomy of individuals who oppose the technology. If the reasons for this opposition are well-founded and the company that is implementing the technology has not taken the appropriate measures to ensure a just distribution of the benefits of the clean process or if the potential risks of the technology for the environment or human health have not been adequately evaluated, the technology enterprise must reconsider its project. Even when bioremediation is considered a safe technology and no risks to the population or the environment are anticipated, public concern against the implementation of this technology can arise. This concern often stems from fears among the affected population, primarily because they lack control over the technology and its effects. To address these concerns, it is necessary to establish democratic procedures that allow the interested parties to express their opinions and participate in the decisions [1] (Fig. **1**).

Fig. (1). Various ethical principles exist in environmental biotechnology, including respect for autonomy, just distribution of benefits, and public participation. The illustration depicts community meetings, discussions about bioremediation projects, and diverse groups of people expressing their opinions in an environmental setting. Figure made with DALL-E.

One of the main goals in the field of environmental biotechnology is the development and commercialization of clean biological processes to restore, preserve, and improve the environment. However, this process may raise some ethical issues. The first is a consequence of the pollution or alteration of an environment that affects two or more communities. In this case, determining which community is entitled to use a certain environment or has the authority to make decisions about the management of that environment can generate a social conflict. Ethical frameworks are required to resolve this potential conflict in the distribution of the benefits of biotechnological processes applied to environmental

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This book is a comprehensive and innovative work that represents a fundamental contribution to the field of environmental biotechnology and sustainable natural resource management.

Throughout its 14 chapters, the book extensively explores the potential of biotechnological techniques as strategies for restoration, conservation, and proper management of soil and water resources.

Unquestionably, this book will be an important and valuable resource for researchers, professionals, students, and decision-makers who will find in this work fundamental support regarding the biotechnological potential in environmental sciences.

In my opinion, this work is destined to become an essential reference in the biotechnology field applied to soil and water conservation. Its publication is particularly timely given the current context of the global water crisis and soil degradation, offering innovative and sustainable solutions to these critical challenges.

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