Chapter 02

2. Biotechnologies Applied to Environmental Issues

2.1. Climate Change and Ecosystem Evolution

Climate change and its potential impacts are now well recognized by major global powers; however, their economic, social, and political institutions have been slow to respond. There is a clear and urgent need for these entities to accelerate and unify their efforts to reduce greenhouse gas emissions and adapt population behaviors to climate change.

To address this, it is essential to:

Increase yields on already cultivated lands.

The enhancement of crop yields is imperative for two primary reasons:

• New lands available for cultivation are scarce, and farmers bear the responsibility of not encroaching upon forests or biodiversity-rich areas, which are also the primary existing carbon sinks.

• The availability of arable land is highly uneven across continents, and due to increasing urbanization, there has been a significant decrease in the amount of arable land available per capita: Between 1960 and 2000, the amount of arable land per capita decreased by 40%. In 1960, there were 4.3 hectares of arable land per person; by 2000, this had dropped to 2.2 hectares per person, and by 2020, it further declined to 1.8 hectares per person.

Currently, the yields of cereal crops are stagnating in Northern countries. Researchers agree that 90% of yield increases will stem from a better understanding of plant biology, improved agronomic practices, and increased utilization of genetics (characterization and potential modification of genomes).

2.1.1. Reduction of Greenhouse Gas Emissions (GHG):

Agriculture currently accounts for 14% of GHG emissions. However, it would have required cultivating between 860 and 1500 million hectares more than in 1960 to achieve current production levels without technological changes. Intensive agriculture, characterized by the adoption of selected seeds, the use of pesticides and fertilizers, irrigation, and mechanization, has increased yields and thus preserved land. Contrary to common belief, it has contributed to a reduction in GHG emissions per ton harvested. Genetically modified organisms (GMOs), by enhancing the performance of existing varieties, further contribute to this reduction in GHG emissions per ton of food produced.

2.1.2. Utility of Herbicide-Tolerant Crops:

A study conducted in Brazil indicates that between 1996 and 2000, the cultivation of genetically modified soybean, corn, and cotton reduced the use of water, fuel, inputs, and CO2 emissions. Specifically, herbicide-tolerant soybean, combined with no-till or reduced tillage techniques, has increased the productivity of this crop by decreasing labor time and reducing the cost of insecticide treatments by 24 to 32%. It has also facilitated double cropping within a year, using both winter and summer varieties.

2.1.3. Upcoming Introduction of Drought-Tolerant Corn:

Numerous research projects on drought tolerance are currently underway worldwide. To maintain yields under water stress conditions, seed companies are employing multiple, often combined, research approaches. The most studied plant is corn, with the first two drought-tolerant varieties expected to be commercialized soon.

2.2. Management of Microbiological, Plant, and Animal Resources:

Until now, collections of organisms (microbial, plant, animal, and human cells) and their components (tissue fragments, nucleic acids, proteins, etc.) were dispersed across various facilities: research centers, laboratories, or hospitals. Accessing these resources was challenging, outcomes were uncertain, and their utilization was not controlled. Therefore, it is essential to consolidate these collections and their organisms within Biological Resource Centers responsible for acquiring, validating, studying, and distributing them. To establish these operations under optimal conditions, four parameters must be considered:

- **Scientific Rigor:** Research and study of gene networks involved in cellular function and dysfunction require biological resources with guaranteed origin and quality.
- **Safety:** The diversity and uncontrolled emergence of collections can pose risks to health and the environment (e.g., dissemination of pathogens).
- **Ethical Requirements:** While there exists a legislative and regulatory framework for the scientific use of collections, it is not fully enforced (particularly regarding human-derived biological resources).
- **Economic Regulation:** Currently, there is evidence of uncontrolled exchanges and irreversible losses. Specific standards for access to biological collections would promote scientific development and rational industrial applications.

Biological Resource Centers have evolved into strategic infrastructures for biotechnology. Ensuring quality and traceability is essential, especially considering the vast opportunities presented by genome analysis and post-genomic studies: identification of genes of interest, modeling, diagnostic and therapeutic applications, biodiversity, and emerging diseases.

To ensure compliance with all procedures, Biological Resource Centers that handle human biological resources will adhere to a forthcoming ethical charter. This charter regulates the origin of samples and corresponding information, processing, transformation, storage, distribution, and/or transfer of biological samples, intellectual property and valorization, as well as the relationships between different Biological Resource Centers.

2.3. Agro-environmental Pollution (Water, Air, Soil)

2.3.1. Bioremediation

It is important to recall that bioremediation is the application of biotechnology to the treatment and reuse of waste products. Let's examine some applications in this field. Biological purifiers are a good example of simple applied biotechnology. In this case, it involves a fixed bed of microorganisms that degrade organic waste products until acceptable levels are achieved in the water to be discharged directly. The sludge from these purifiers is used as biomass for animal feed. There are also biotechnological processes for treating urban solid waste using aerobic or anaerobic fermentations to produce biogas. Another example of this technique includes testing treatments for point-source problems using biotechnology, such as the digestion of oil spills in the ocean by microorganisms following a tanker accident that led to a discharge.

2.3.2. Decontamination (Water, Air, Soil)

Currently, biotechnologies are primarily used to combat pollution. One of the first applications was the treatment of wastewater, followed by air purification and gaseous effluents. Biological decontamination is increasingly focusing on soil.

2.3.2.1. Microbiological Decontamination of Water

The treatment of wastewater heavily relies on biotechnologies: biological treatment allows for a much more efficient cleaning of a wide range of effluents than physico-chemical methods and is particularly suitable for those containing the most common organic pollutants. In fact, its use for wastewater treatment dates back over a hundred years.

Since then, both aerobic and anaerobic processes have been developed. Aerobic treatment has become the most common solution for lightly to moderately loaded effluents, as well as for toxic and recalcitrant molecules. Anaerobic processes are more effective for highly organic effluents, such as wastewater from food processing plants, urban sludge, and livestock waste, and have begun to replace aerobic systems in many applications over the past decade. Anaerobic treatment facilities are more compact, separating carbon compounds to produce combustible gas, methane, and offering recovery rates exceeding 80%. Biotechnological methods are now widely used to extract nitrates, phosphates, heavy metal ions, chlorinated organic compounds, and toxic substances. While the initial goal of wastewater treatment was primarily to reduce organic matter in general, the neutralization of industrial pollutants is now increasingly important, which is why efforts are underway to develop biological processes for extracting specific pollutants.

2.3.2.2. Microbiological Decontamination of Air

The use of microorganisms in the treatment of gaseous pollution is a relatively recent approach that relies on their ability to utilize pollutants in their metabolism to produce the energy necessary for cellular development.

For a better understanding of biotechnologies applied to reducing atmospheric pollution, such as desulfurization and denitrification of flue gases, removal of toxic products like organochlorines, deodorization, and volatile organic compounds (VOCs), some concepts of microbial metabolism are presented in this section. The use of microorganisms in biological treatments relies on their ability to utilize certain undesirable molecules for humans and the environment as substrates. Indeed, microorganisms, particularly bacteria, exhibit several capabilities, including:

- Rapid propagation with relatively short generation times.
- Significant flexibility in regulating, coordinating, inducing, and repressing metabolic pathways.
- Quick colonization of new habitats.
- Tolerance to extreme environmental conditions.
- Association with other organisms in synergistic interactions such as symbiosis, mutualism, and commensalism, thereby expanding the metabolic diversity of a species. Biotechnological processes used for air and gaseous effluent treatment primarily include:
- Biofilters,
- Biowashers,
- Percolation filters.

2.3.2.3. Microbiological Decontamination of Soils

Numerous companies specialize in soil decontamination. Although treatment methods may differ, the methodological approach remains consistent.

<u>The first step:</u> involves assessing the "damage." What is the extent of the pollution? Is it superficial or deep? What are the immediate dangers? What are the geological and hydrological data of the site?

The second step: is critical. Laboratory analysis allows for the examination of the nature of the pollution. Simultaneously, "microorganisms" are isolated from the contaminated site and tested to determine their biodegradative capacity. In some cases, at sites being rehabilitated, microorganisms have already initiated degradation. The isolation of these strains and the characterization of their nutritional requirements will help determine which nutrients need to be added to accelerate their development.

The speed and degree of pollutant degradation depend on numerous parameters that must be optimized, including:

- The concentration and nature of the pollutants,
- Interactions between different pollutants,
- Nutrients (sources of nitrogen, phosphate, minerals),
- Electron acceptors (oxygen, nitrate, etc.),
- Moisture (water activity plays a crucial role in biodegradation),
- Temperature,
- Soil structure.

The third step: specifies the technique. Should biodegradation occur "in situ," "on site," or off-site?

In situ Treatment: This is the preferred technology:

- When contamination is shallow, the soil can be enriched with microorganisms and nutrients, potentially tilled mechanically to promote oxygen transfer; the water resulting from the treatment is purified in a bioreactor.
- When the soil to be decontaminated is not accessible (occupied by structures) or when contamination is very deep and has already reached the groundwater.
  In "in situ" treatments, the nature of the electron acceptor plays an important role. Oxygen, hydrogen peroxide, or nitrates can be used.

On-site Treatment: After excavation, the soil is treated on-site using appropriate technologies:

- In bioreactors. - In windrows. - In piles.

To achieve this, the contaminated soil is homogenized, enriched with products that improve its structure (such as shredded straw); the soil is watered, enriched with nutrients and microorganisms (if applicable), and shaped into either windrows or piles.
The soil is regularly turned to ensure good oxygen transfer. As temperature plays an important role, efforts are made to control it as much as possible (with piles or windrows being covered).

Off-site Treatment: Several industries offer to treat polluted soils at "waste treatment centers" using techniques involving more efficient reactors, sometimes combining soil, water, and gas treatment.

Transportation costs are high, but the efficiency of the equipment can sometimes accelerate the biodegradation process and thus reduce treatment costs.

The fourth step: involves monitoring the process, which typically takes several months (in situ or on-site). Analytical monitoring allows for the assessment of:

- The disappearance of pollutants.
- The possible emergence of new molecules.
- Biodegradation kinetics to verify the performance of strains concerning their biodegradative capacities (evaluated in the laboratory) in order to adjust nutrient inputs if necessary.