ENVIRONMENTAL BIOTECHNOLOGY - SOCIO-ECONOMIC STRATEGIES FOR SUSTAINABILITY

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Contents

Summary

Environmental biotechnology is concerned with the application of biotechnological techniques to foster and preserve the environment, which means to keep a balance between the physical and biological matters on this planet. The basis for such a balance can be found in the form of the natural cycles of matter. It is therefore of utter importance to find techniques and scientific applications to be able to foster, improve and increase the activities of these natural cycles in order to cope with an increasing human and animal population.

In order to sustain life and improve the standard of living, the general advancement of scientific knowledge of clean technological strategies, which support the natural cycles of matter. Sustainability can be obtained together with a higher health and living

standard, if appropriate technologies are applied according to the climatic region and local society. This article together with those within this Topic will demonstrate that it is possible to return to a balanced environment with better health and living conditions.

In order to be able to use these specific biotechnological techniques, this article firstly demonstrates how nature itself copes in recycling its natural wastes most efficiently. Attention is drawn continuously to those areas of the various cycles where human activities have interfered causing an imbalance of dangerous proportions in the cycles.
To sustain life and improve the standard of living has to become also a concern of each and every community, society and individual. Only with their concerted effort can we finance and establish a balanced cycling of matter. Since these efforts require strong societal input, the term socio-economic is being used and a suggestive scheme of community involvement is being presented.

The question arises, of course, how nature is able to cope with an increasing human population, which automatically results in a higher animal population and demand for food and feed and energy. A socio-economic strategy for sustainability has to take these demands into consideration. It must therefore be the aim of environmental biotechnologists to improve more rationally food and feed production through a multi-product agricultural system exploiting more thoroughly our available natural renewable resources. Examples are given for agricultural farming and agro-industrial manufacturers employing starch, carbohydrate and lignocellulosic materials. At the same time, increasing wastes can be handled with an improved methanogenesis connected to additional food, energy and fertiliser production reducing increased carbon dioxide levels in the atmosphere. Biofertilisation and energy are very important since the soils have to be replenished as is shown in the nitrogen cycle. The examples also indicate, that biofuel can be part of the strategies.

1. Introduction

In order to sustain life and improve the standard of living, the general advancement of scientific knowledge should be used for the application of clean technological strategies, which support the natural cycles of matter. These strategies should strive towards a pollution-free environment, resulting in the prevention of diseases and an improvement of our natural cycles of matter to increase our renewable resource production. At the same time they need to be flexible to guarantee the rural farmer and the urban workforce a sustainable per capita income.

Sustainability refers therefore to the ability of a society, ecosystem or any such ongoing system to continue functioning into the indefinite future without being forced into decline through exhaustion of key resources. A sustainable community effort consists therefore of a long-term integrated systems approach to developing and achieving a healthy community by jointly addressing economic, environmental, and social issues. Fostering a strong sense of community and building partnerships and consensus among key stakeholders are important elements of such efforts. The focus and scale of sustainability efforts depends therefore on local conditions, including resources, politics, individual actions, and the unique features of the community.

Socio-economic strategies have therefore to be designed in a way that individual choices are shaped by values, emotions, social bands, and judgements rather than a precise calculation of self-interest. It assumes that the economics are embedded in society and culture and is not a self-contained system. This implies also that societal sources of order are necessary for markets to function efficiently.

This revolutionary thought may require sacrifices, particularly in the developed countries, through reductions in profits, product range, and product variability in return for a stable and less polluted environment. It seems there is little choice but to accept these sacrifices as it becomes more and more clear that the earth and its atmosphere can not continue to act as an infinite sink for the waste products of industry, agriculture and urban living. Waste management must become an integral part of the manufacturing industry, turning it from a monoculture/mono-product into a multiproduct system.

It is important to realise that as living standards rise, the consumption of livestock products will increase. The feeding systems to produce these products, especially in developed countries, use the same feed resources as are consumed by the human population. It has been estimated that almost 50 percent of the world grain supply is consumed by livestock, which has to be changed to secure food for an increasing population to be fed. Recycling plays an important role in the endeavour to integrate livestock and crop production. Integrated farming systems, which embody these concepts are seen in many parts of SEAsia [see also - Recycling of organic wastes using integrated biosystems in rural farming] and have developed in response to increasing human pressure on land resources.

In order to be able to use biotechnological techniques to improve and sustain our environment and at the same time improve the standard of living, it is important to firstly receive an appreciation of how nature works and tries to keep its balance of sustainability before we try to design and improve environmental management to help nature under the increasing pressure of waste production and accumulation.

2. Nature's Cycles of Matter

2.1. General Description

Biogeochemical cycling describes the movement and conversion of materials by biochemical activities within the ecosphere through which elements circulate in characteristic paths or cycles between the biotic and abiotic portions of the ecosphere. This cycling occurs on a global scale, producing profound effects on the geology and present environment of our planet. Biogeochemical cycles include physical transformations, such as dissolution, precipitation, volatilisation and fixation; they also include chemical transformations such as biosynthesis, biodegradation, oxido-reductive biotransformations, as well as various combinations of physical and chemical changes. Biogeochemical cycling is driven directly or indirectly by the radiant energy of the sun. Energy is absorbed, converted, temporarily stored and eventually dissipated, which means that energy flows through ecosystems. Whereas energy flows through the ecosystem, materials undergo cyclic conversion that tend to retain materials within the ecosystem.

The intensity or rate of biogeochemical cycling for each element roughly correlates to the amount of the element in the chemical composition of biomass. The major elemental components of living organisms (C, H, O, N, P, and S) are cycled most intensely.

Microbiologically mediated portions of biogeochemical cycles are essential for growth and survival of plant and animal populations. Some of the critical metabolic activities of microorganisms that directly influence plant and animal populations are well known to microbiologists. It is important to recognise that the biogeochemical cycling activities of microorganisms determine, in large part, the potential productivity that can be supported within a habitat. Alterations in the biogeochemical cycling activities of microbial populations caused by human activities [pollution etc] can result in changes in the transfer rates of elements between reservoirs and the size of the reservoirs of elements in particular chemical forms within habitats. Such a change alters the biochemical characteristics of a habitat and the populations that can be supported, both in quantitative and qualitative terms.

The turnover of the elements that compose living organisms constitutes what we refer to as the cycles of matter. All organisms participate in various steps of these cyclic conversions, but the contribution of microorganisms is particularly important, both quantitatively and qualitatively.

2.2 The Carbon Cycle

When examining the cycles of an individual element, it is useful to consider first the global reservoirs of this element, the size and whether or not these reservoirs are being actively cycled. The most actively cycled reservoir of carbon (Figure 1) is atmospheric CO_2 (0.03 percent of the atmosphere). The dissolved inorganic forms of carbon (CO_2, H_2CO_3, HCO_3^-, and CO_3^{2-}) in surface water are in direct equilibrium with the atmospheric CO_2. The living biomass in terrestrial and aquatic environments contains slightly less carbon than the atmosphere.

The natural rate of carbon cycling in oceans and on land are close to a steady state, that is, the rates of movement of carbon between the atmosphere and trees or between algae and the dissolved inorganic carbon of the oceans do not change measurably from year to year and tend to balance each other. However, human activities have recently introduced changes in the carbon cycle that are large enough to be measured. For example the flux of carbon from algae into dissolved organic carbon in the open ocean is at steady state because human activities are not as yet great enough to perturb the rate. In contrast, the reservoir of carbon (as CO_2) in the atmosphere is no longer in a steady state and is growing from year to year. Thus, the global carbon cycle is out of balance. Atmospheric CO_2, because it is a relatively small carbon pool, has been measurably affected by industrial CO_2 release.

As can be visualised from Figure 1, the concentration of CO_2 is largely set by the competing processes of photosynthesis and respiration [see - Cell thermodynamics and energy metabolism]. Under favourable environmental conditions of light intensity and temperature, the rate of photosynthesis and therefore the rate of plant growth is limited by the concentration of CO_2 available to the plant.

When CO_2 is dissolved in slightly alkaline water, bicarbonate (H_3CO^-) and carbonate (CO_3^{2-}) ions are formed as was mentioned earlier:

$$CO_2 + OH^- \longrightarrow HCO_3^-$$

$$HCO_3^- + OH^- \longrightarrow H_2O + CO_3^{2-}$$

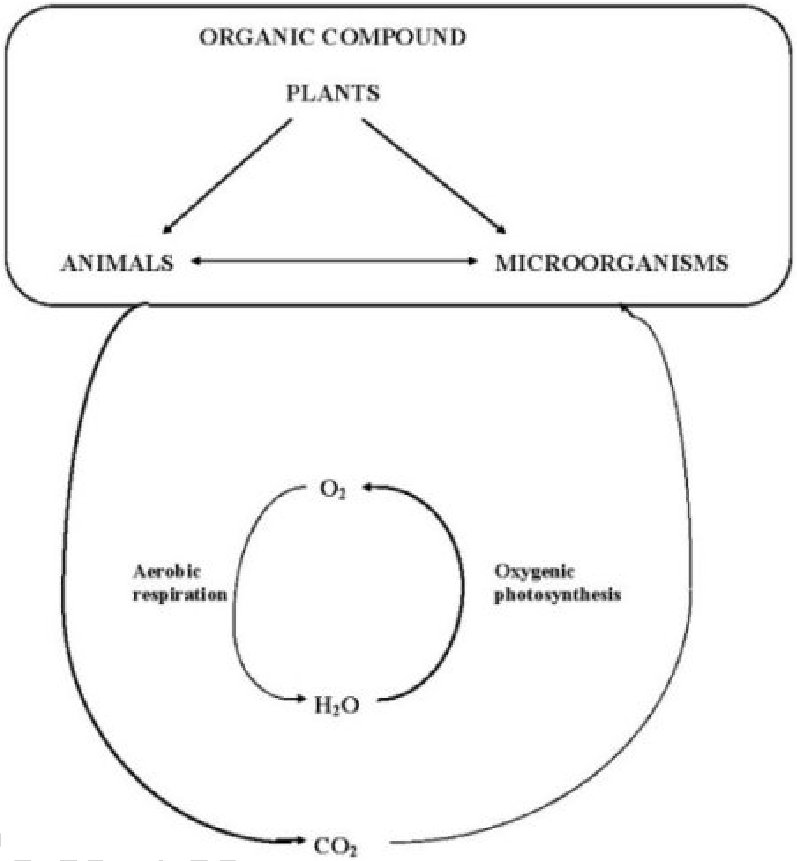

Figure 1: The Carbon Cycle in Nature

Therefore, bicarbonate serves as the reservoir of carbon for photosynthesis in aquatic environments. The bicarbonate concentration of ocean waters acts as reservoir for CO_2 produced on land, keeping its atmospheric concentration at a relatively low and constant level.

The carbonate ions in the oceans combine with dissolved calcium ions and become precipitated as calcium carbonate. The latter is also deposited biologically in the shells of protozoan, corals, and molluscs. This is the geological origin of the calcareous rock or limestone that is an important constituent of the surface of the continents. The formation and solubilisation of calcium carbonate are brought about primarily by changes in hydrogen ion concentration, and microorganisms contribute indirectly to both processes as a consequence of pH changes that they produce in natural environments. For example, such microbial processes as sulfate reduction [see Section

2.4.3] and denitrification [see Section 2.3.3] cause an increase in alkalinity of the environment, which favours the deposition of calcium carbonate in the ocean and other bodies of water.

Microorganisms also play an important role in the solubilisation by production of acid during nitrification [see Section 2.3.2], sulfur oxidation [see Section 2.4.1] and fermentation.
As a general principle, anaerobic environments tend to serve as sinks in which organic materials accumulate because fewer organic materials can be metabolised anaerobically than aerobically. But ***methanogenesis*** [see below] provides a major route by which organic material can escape from an anaerobic environment to an aerobic one, where it can be metabolised further to CO_2 and H_2O. Sulfate reducing bacteria also play an important role in oxidising products of fermentation.

Since the industrial revolution, human exploitation of the stored deposits of organic carbon in the earth's crust has resulted in their rapid mineralisation. A consequence of this very rapid burning of fossil fuels has been an increase in the rate of production of CO_2 over the rate at which it is utilised in biological fixations. Over the past 100 years the net increase of CO_2 in the atmosphere has been about 15 percent. Although this increase is relatively small, if it continues, its impact could be profound because atmospheric CO_2 tends to prevent the loss of radiant energy from the earth, thus causing its average temperature to increase, perhaps to dangerous levels (*greenhouse effect*). This danger could be counteracted by increasing the photosynthesis by about 1 percent and a balance could be restored.

The rapid increase in the total size and local density of human population that has occurred over the past century contributed also to modifications in the environment and thus modifying not only the carbon cycle, but also all other cycles as will be discussed below. Within the past century these factors have led to local environmental changes comparable in scale to those produced by major geological upheavals in the past history of the earth. The spread of agriculture, the de-nudation of forests, the mining and burning of fossil fuels, and the pollution of the environment with human and industrial wastes have profoundly affected the distribution and growth of other forms of life. As a result of the concentration of the human population in large cities, the disposal of organic wastes, both domestic and industrial , has become a major ecological problem

2.3 The Nitrogen Cycle

The nitrogen cycle is the conversion of nitrogen between the different forms in the biosphere (Figure 2). Nitrogen gas is the most abundant gas in the atmosphere. Although molecular dinitrogen is abundant, constituting about 80 percent of the earth's atmosphere, it is chemically inert and therefore not a suitable source for most living forms. Yet all plants, animals and most microorganisms require some form of nitrogen to produce amino acids and thereby proteins, nucleic acids and, in the case of bacteria, cell wall materials. Access to an adequate supply of nitrogen in some form is a pre-requisite for all forms of life, but combined nitrogen in the form of ammonia, nitrate and organic compounds is relatively scarce in soil and water, often constituting the limiting factor for the development of living organisms. For this reason, the cyclic transformation of nitrogenous compounds is of paramount importance in supplying required forms of nitrogen for the various classes of organisms in the biosphere. Thus, the nitrogen atom can be in many different oxidation states and many of the *shifts* between these states are mediated by microorganisms. Nitrogen exists most easily in the gaseous state.

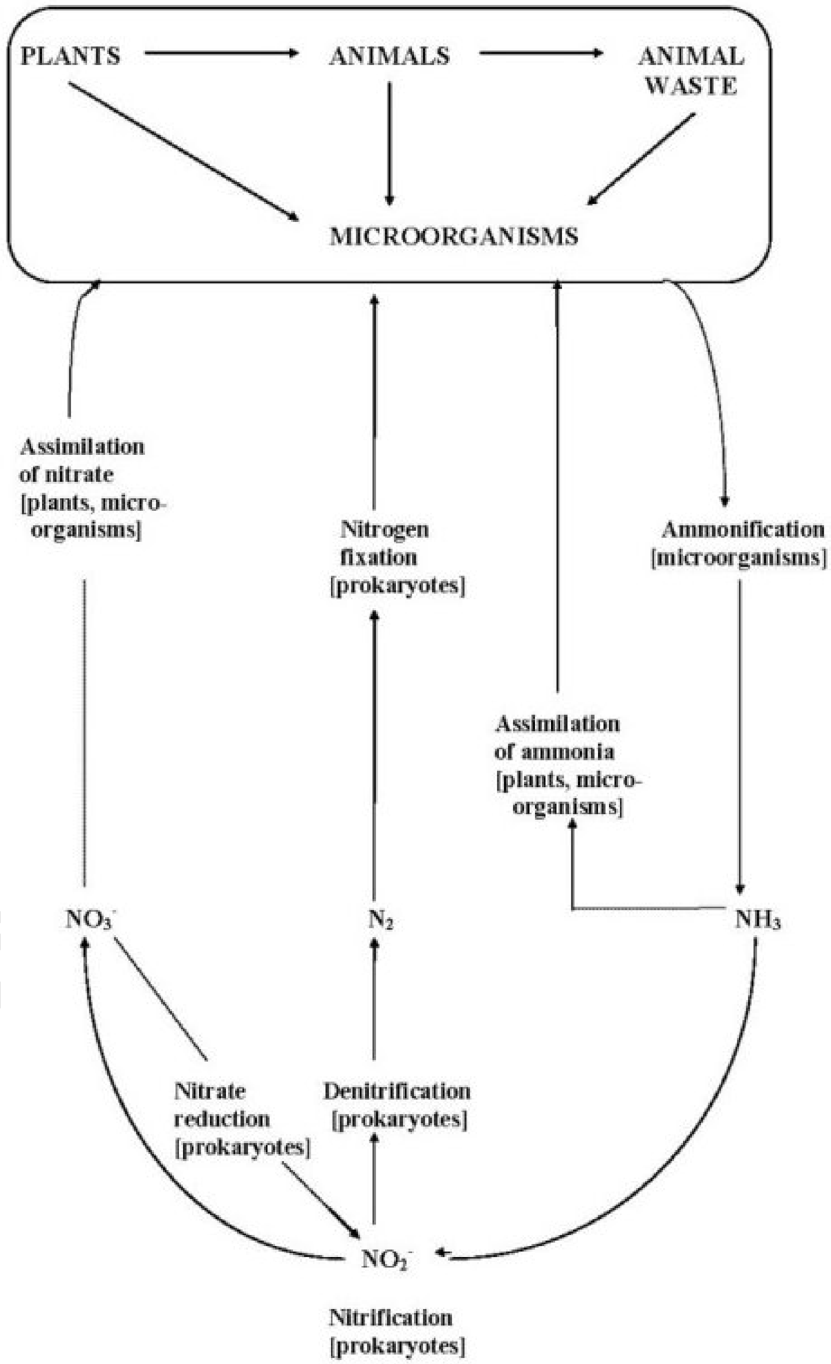

Figure 2: Nitrogen Cycle

Biologically, only bacteria can ***fix*** atmospheric nitrogen gas into forms available for metabolism. Microorganisms are primarily responsible for most of the cycling of nitrogen in the biosphere. This nitrogen cycling is often simplified as shown in Figure 3.

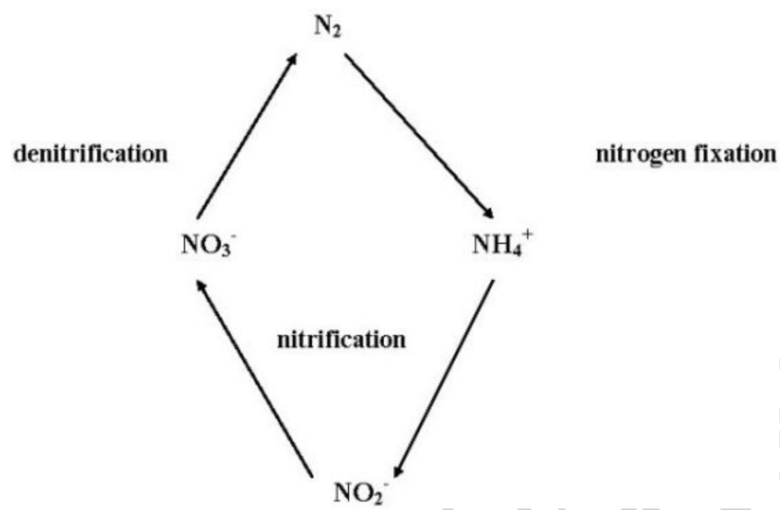

Figure 3: Simplified Nitrogen Cycle

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Biographical Sketches

Horst W.Doelle, born in 1932, studied biology at the University of Jena [1950-1954]. He studied for his doctorate at University of Goettingen [1955-1957] on antibiotic production. After receiving his doctorate, he worked in the Wine and brewing industry in Germany before taking up an appointment with CSIRO in Australia in 1960. After 4 years wine research, he took up the challenge to build up microbial physiology and fermentation technology at the Department of Microbiology at the University of Queensland in Brisbane. He received his Doctor of Science in 1976 and his Doctor of Science honoris causa in 1998. He perticipated and conducted numerous training courses in developing countries. After 29 years teaching he retired in 1992. His research area was regulation of anaerobic/aerobic metabolism, microbial technology [*Zymomonas* ethanol technology] and socio-economic biotechnology using microorganisms for waste management.

Poonsuk Prasertsan, born in 1953, studied in Food Science & Technology at Kasetsart University, Bangkok (1973–1977). She had worked in a fruit and vegetable canning factory for nearly two years, then decided to study for Master Degree in Biotechnology at the University of Queensland (UQ), Australia (1979-1981). After graduation, she worked as a lecturer at Prince of Songkla University (PSU), Hatyai. She received AIDAB Scholarship to pursue Ph.D study (Biotechnology) on enzyme (cellulase, xylanase) production at UQ (1983-1987). After receiving her doctorate, she continued her academic career at the Department of Industrial Biotechnology, Faculty of Agro-Industry, PSU and teaches in Biotechnology, Fermentation Technology, Enzyme Technology, Waste Utilization, and environmental related subjects, etc., at graduate and postgraduate levels. Besides teaching, she has been active in research in the field of waste utilization and treatment, as well as clean technology. She has been a research fellow under JSPS Program in Biotechnology for several times and has received the Certificate for Lead Accessor Course in ISO 14000. In 1993 and 1995, she was involved in the projects entitled “Oil Recovery from Palm Oil Mill Effluent” and “Environmental Management Guideline for the Palm Oil Industry”, supported by Deutsche Gessellschaft fur Technische Zusammenarbeit (GTZ), Germany and the Department of Industrial Works, Ministry of Industry, Thailand. Now she is working on several projects such as process development for the production of photosynthetic bacteria and their applications; valuable products from agro-industrial wastes particularly seafood processing and palm oil mill wastes; biopolymer production from thermotolerant isolates and the strains isolated from wastewater treatment plant, etc.