Microorganisms and biogeochemical cycles biology essay

Microorganisms are known to have existed from the very beginning of life, about 3, 500 millions of years ago while animals and plants have appeared only about 3000 millions of years after. Microorganisms are defined as microscopic organisms which cannot be seen with an unaided eye and they consist of bacteria, yeasts, protozoa, fungi and viruses. The first recorded observations of some of the microorganisms were made by Dutchman Antonie van Leeuwenhoek in 1675 by a simple microscope. However it was only the improved microscopes in the mid 19th century that have allowed many scientists to explore the microbial world. Development in the world of science and technology has helped to illustrate that microorganisms are everywhere in the environment.

Microorganisms play an important role in maintaining the balance of nutrients and waste products in the biosphere. They help to preserve the natural environment by controlling the biogeochemical cycles in the soil. Such cycles consist of the nitrogen, carbon, sulphur, phosphorus and oxygen cycles.

The nitrogen cycle can be considered as the most important cycle for nitrogen is an important component of all living cells. Nitrogenous compounds include amino acids, nucleic acids and certain co-enzymes which are vital to life. The most common form in which nitrogen exists is in the gaseous state, N2 where the atoms form strong covalent bonds. These bonds can only be broken in the presence of a high amount of energy or certain bacteria. In fact, each step of the nitrogen cycle requires various types of bacteria. Microbial nitrogen transformation involves 3 major processes namely the nitrogen fixation, nitrification and denitrification.

Figure 1: The nitrogen cycle. Yellow arrows indicate human sources of nitrogen to the environment. Red arrows indicate microbial transformations of nitrogen. Blue arrows indicate physical forces acting on nitrogen. And green arrows indicate natural, non-microbial processes affecting the form and fate of nitrogen.

Nitrogen fixation is the process by which nitrogen in the atmosphere is converted into ammonia. Nitrogen fixation is carried out by diazotrophs. They are either photoautotrophs (cyanobacteria) or free-living chemoheterotrophs (e. g. Azotobacter), or symbiotic chemoheterotrophs (e. g. Rhizobium). These organisms are specialised to keep the oxygen concentration low. Certain species achieve it by having a high respiratory rate, e. g. Klebsiella pneumoniae, Bacillus polymyxa, and Bacillus macerans. Other bacteria have specialized cells (heterocysts) that lack the oxygen generating steps of photosynthesis. Examples are Anabaena cylindrica and Nostoc commune. Other cyanobacteria lack heterocysts and can fix nitrogen only in low light and oxygen levels (e. g. Plectonema). Nitrification is the conversion of ammonia to nitrate (NO3-1). Nitrifying bacteria include species of Nitrosomonas and Nitrosococcus. Nitrosomonas species convert ammonia to nitrite (NO2-1) while Nitrosococcus species convert the nitrite to nitrate (NO3-1). Nitrification occurs in soils, fresh water, and marine environments. The nitrate that results serves as an important nitrogen source for plants. Denitrification is the process whereby nitrates are converted back to ammonia or even nitrogen gas, to return into the atmosphere. Denitrification takes place in terrestrial and marine ecosystems where bacteria respire nitrate as a substitute terminal electron acceptor. The process is generally carried out by chemoheterotrophs e. g. Paracoccus denitrificans. One particularly important group of denitrifiyers is Annamox which contributes up to 50% all N2 produced in oceans.

Carbon is another important element for life as it makes up every organic compound. Despite the fact that carbon is the foundation for all life, its concentration must be kept constant.

Diagram 2: The Carbon Cycle (Units are in gigatons of carbon)

Carbon occurs in many forms such as limestones (calcium carbonate), dissolved in oceans and fresh water and in the atmosphere as carbon dioxide. An example of a carbon cycle is the microbial digestion of cellulose. The carbon cycle takes place in two stages: oxic and anoxic.

Carbon fixation is carried out by photoautotrophic and chemolithotrophic bacteria such as Synechococcus and Thiobacillus respectively. The cycle consists mainly of one group of bacteria aerobically converting methane to CO2 (Methanotrophy) while another group convert CO2 to methane (Methanogeneis).

Diagram 3 showing an overview of the organisms involved in the carbon cycle.

Microorganisms and food production

Two centuries after Antonie Van Leeuwenhoek discovered microorganisms using his microscope, French scientist Louis Pasteur published his first report on lactic acid formation from sugar by fermentation. He published a detailed report on alcohol fermentation later in 1860. Fermentation is the metabolism of pyruvate without oxygen and is used in food and drink industries such as in the production of bread, alcohol, dairy products, flavourings and vinegar. The bacterium Saccharomyces cerevisiae is used in the production of bread where it ferments sugars derived from starches in wheat to ethanol and CO2, which are expelled and trapped respectively to give the lightness and texture to the bread.

In the production of milk and milk products, Streptococcus species including S. cremoris and S. lactis ferment and acidify milk while lactic acid bacteria convert milk sugar lactose to lactic acid. Yoghurt is made by heating milk and fermenting at 40°C with bacteria such as Lactobacillus bulgaricus which produces acetaldehyde (as well as lactic acid) that gives the yoghurt its characteristic tart taste. Nowadays yoghurt drinks which contain probiotic bacteria have become increasingly popular for they help to prevent the host from acquiring diseases.

Microorganisms and biofuels

With the limited natural oil resources and the increase in pollution, the field of biofuels has become a rapidly developing area of research. Anaerobic micro-organisms can convert biomass into useful energy sources. It involves a type of fermentation process that produces carbon dioxide and methane. The ‘ biogas’ produced can then be used as fuel. Alternatively, scientists are developing processes that exploit photosynthetic bacteria or algae. These micro-organisms can capture sunlight to produce new biomass that can be turned into alternative sources of energy. Bioethanol can also be produced through fermentation as in beer production, sugar is extracted from crops and fermented. Bioethanol is biodegradable, low in toxicity and can be used as an alternative for petrol in cars or mixed with petrol to produce fuels that have lower emissions when burnt.

Microorganisms and water treatment

Water treatment removes undesirable chemical and biological contaminants from raw water. The aim is to produce water fit for a specific purpose generally for drinking water. Water is the most important potential common source of infectious diseases and consequently water purification is important to ensure public health. Many of the methods used in managing water quality depend on standardised microbiology techniques as microbes are used to identify problems and to remove and degrade organic material. One of this process is called bioaugmentation which is the seeding of certain microorganisms to improve the quality of water. The microorganisms used include the Enterobacteriacea species, anoxic bacteria, methanogenic archae and certain proteobacteria such as the Pseudomonas, Zoogloea and Sphaerotilus species.

Diagram 4: General process of bioaugmentation which consists of seeding microorganisms to improve water quality.

Microorganisms and biochemicals

Microorganisms are also used in the production of biochemicals such as amino acids, industrial enzymes and plastic resins. Glutamic acid, commonly known as monosodium glutamate (MSG) is an additive often used as a flavour enhancer in food. MSG can be made by Corynebacterium glutamicum which ferments carbohydrates with a nitrogen source. The use of microorganisms to prepare MSG has helped to lower production costs and environmental load. Citric acid which is another food additive can be manufactured by Aspergillus niger from molasses. Lysine, which is an important nutritional element for farm animals can be synthesised chemically however it would be impossible to separate the D and L isomers. The use of microorganisms produces only the L-isomers which are more important.

Microbial cultures can be used to make industrial enzymes such as proteases, amylase and rennin. These enzymes are important in several industries and for domestic purposes such as leather making, meat tenderising, textiles, baking, brewing, chocolate, paper, laundry and dairy industry. Itaconic acid, used as plastic resins is made from citric acid by Aspergillus terrens.

Diagram 5: Plastic resins which can be used to make soft drinks bottles. These resins are made biologically instead of cracking natural hydrocarbons.

Microorganisms and human health

Many microorganisms form an endosymbiotic relationship with higher species such as humans and animals. The surface tissues in humans are usually colonised by various species of microorganisms which form part of the normal human flora. The normal flora of humans consists of a few eucaryotic fungi and protists, but bacteria are the most numerous and obvious microbial components of the normal flora.

Diagram 6 shows a Gram's stain of a species of Micrococcus, commonly isolated from the skin and nasal membranes of humans.

It is known that microbes in the human body make up to more than a 100 trillion of cells, about tenfold than the number of human cells. The majority of microbes resides in the gut, has a profound influence on human physiology and nutrition and is crucial for human life. One such bacterium is E. coli which produces vitamin K2 which is vital for the human body. Other bacteria contribute to the ' barrier effect' which prevents the colonization of pathogens.

Microorganisms and medicine

Microbes have been used to produce valuable chemicals such as antibiotics since the 1940s. Antibiotics are produced by micro organisms inhibit the growth of other micro organisms even at very low concentrations. The first antibiotic to be isolated was penicillin which was discovered by Alexander Fleming in 1929 and was produced on large scale using cultures of Penicillium notatum. Fungi, bacteria and actinomycetes are important antibiotic producing organisms. Most species of Streptomyces are quite active in the production of a variety of antibiotics. Studies in recent years have also been conducted to produce new antibiotics that are more effective than the existing ones, using micro organisms. For example, Bacillus megaterium IFO 12108 has been used to convert antibiotic lankacidin C (+ methyl butyrate) into lankacidin C butyrate, which has an improved antimicrobial activity with reduced toxicity.

Vaccines are also made by using killed microbes or its toxins so that the body can recognise the pathogen, hence increasing the immune system against that particular pathogen. The evolution of vaccines has led to the eradication of many diseases such as polio, small pox and cholera.

Microorganisms have proved to be beneficial to mankind in many ways. Health and life standards have increased due to the human exploitation of microbes. Studying microbes has led to the production of various amounts of food, biochemicals and antibiotics. Moreover, water quality has improved which has caused a decrease in the number of water borne diseases. Some microorganisms may cause diseases but most of them are quite beneficial.