UNIT 7 MICROBES IN GREENHOUSE GASES MITIGATION

Structure

7.1 INTRODUCTION

The Earth is surrounded by a thick layer of gases which work like a blanket. Without this blanket the Earth would be 20–30°C colder and much less suitable for life. Climate change is happening because there has been an increase in temperature across the world. This is causing the earth to heat up, which is called global warming. Global warming can be defined as the increase in the temperature of the earth atmosphere due to human activities. (Panikov, 1999)

The major cause of global warming is the greenhouse gases which traps the heat energy reflected by the earth's surface. The major greenhouse gases are carbon dioxide, methane, nitrous oxide and ozone. Some microbes are solving the problem of global warming gases. The microbes, found in geothermal areas in acidic and hot environment, utilizes methane gas. These microbes can consume huge amount of methane about 11 kg/year and can be helpful in reducing methane emission from methane producing factories and landfills. *Methylobacillus* are one of earth's most important carbon recycler and they recycle carbon compounds as methane, methanol and methylated amines. Besides, there are some naturally occurring microbes that convert carbon dioxide into calcium carbonate that can fetch minerals of economic value. Thus microbes have great potential to fight against global warming and can serve as a powerful tool to combat pollution (IPCC. 2007).

Microbes play an important role in the production and consumption of powerful greenhouse gases including CO_2 and methane, have negative and positive feedback responses to temperature changes, and play a vital function in the regulation of ocean acidity. All of these can suffer perturbations due to anthropogenic climate change. They also have important functions in agriculture and the food web (Briones et al, 2004)

Microbes plays significant roles in the cycling of three major greenhouse gases: carbon dioxide, methane, and nitrous oxide. Land management practices that increase the amount of carbon (organic matter) stored in soil are reducing the amount of CO_2 released to the atmosphere.The capture, sequestration, and utilization of CO_2 is an effective way to decrease the atmospheric CO_2 concentration (Sanford et al, 2012)

7.2 OBJECTIVES

After reading this unit you should be able to:

- Define Climate change.
- Describe different sources of greenhouse of gases.
- Describe Greenhouse gases in soil.
- Describe different natural resources which sequestrationof Greenhouse Gases.
- Explain Role of enzymes in mitigation of CO_2.

7.3 CLIMATE CHANGE

Most scientists now agree that climate change is taking place. This is being demonstrated globally by the melting of the polar ice sheets and locally by the milder winters we are having, coupled with more extreme weather such as heavy rain and flooding.

The Earth is surrounded by a thick layer of gases which keeps the planet warm and allows plants, animals and microbes to live. These gases work like a blanket. Without this blanket the Earth would be 20–30°C colder and much less suitable for life. Climate change is happening because there has been an increase in temperature across the world. This is causing the Earth to heat up, which is called global warming.

7.4 CAUSES OF GLOBAL WARMING

The blanket of gases that surrounds the Earth is getting much thicker. These gases are trapping more heat in the atmosphere causing the planet to warm up.

7.4.1 Source of Greenhouse Gases

These gases are called greenhouse gases. The three most important greenhouse gases are carbon dioxide, methane and nitrous oxide and these have increased dramatically in recent years due to human activity.

The Earth is known as a 'closed system' which means that it produces everything it needs to ensure the survival and growth of its residents. In nature there are chemical cycles such as the carbon cycle to control and balance these gases that surround the Earth. The carbon cycle is a complex series of processes through which all of the carbon atoms in existence rotate. This means that the carbon atoms in your body today have been used in many other molecules since time began e.g. as the carbon found in carbon dioxide in the air. Microbes play an important role as either generators or users of these gases in the environment as they are able to recycle and transform the essential elements such as carbon and nitrogen that make up cells (Willey et al, 2009) . Global Greenhouse Gas Emission by Gas is given in Figure 7.1.

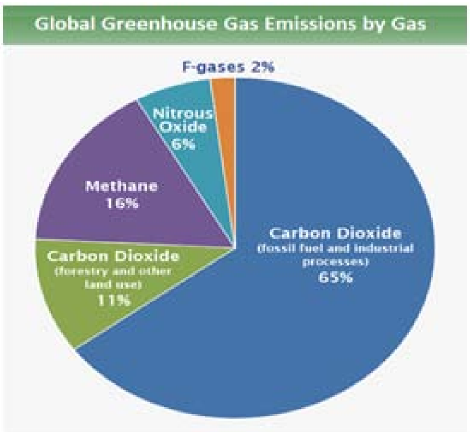

Figure7. 1: Global Greenhouse Gas Emission by Gas (Source: Willey et al, 2009)

Bacteria and archaea are involved in the 'cycles' of all the essential elements. For example:-In the carbon cycle methanogens convert carbon dioxide to methane in a process called methanogenesis. In the nitrogen cycle nitrogen-fixing bacteria such as *Rhizobium* fix nitrogen, which means they convert nitrogen in the atmosphere into biological nitrogen that can be used by plants to build plant proteins. Other microbes are also involved in these cycles. For example:-Photosynthetic algae and cyanobacteria form a major component of marine plankton. They play a key role in the carbon cycle as they carry out photosynthesis and form the basis of food chains in the oceans (Jenkinson et al, 1991). Fungi and soil bacteria the decomposers play a major role in the carbon cycle as they break down organic matter and release carbon dioxide back into the atmosphere.

7.4.2 Can Microbes Help Save the Planet

Microbes play an important role as either generators or users of these gases in the environment as they are able to recycle and transform the essential elements such as carbon and nitrogen that make up cells. Bacteria and archaea are involved in the 'cycles' of all the essential elements e.g. in the carbon cycle methanogens convert carbon dioxide to methane in a process called methanogenesis; in nitrogen cycle nitrogen-fixing bacteria such as Rhizobium fix nitrogen there by converting nitrogen in the atmosphere into biological nitrogen that can be used by plants to build plant proteins. Other microbes are also involved in these cycles' e.g. photosynthetic algae and cyanobacteria form a major component of marine plankton. They play a key role in the carbon cycle as they carry out photosynthesis and form the basis of food chains in the ocean. Fungi and soil bacteria are the decomposers that play a major role in the carbon cycle as they break down organic matter and release carbon dioxide back into the atmosphere (Melillo et al, 2002).

Greenhouse gas fluxes in terrestrial ecosystems, atmospheric carbon dioxide (CO_2) is fixed into sugars by the autotrophic (mainly plant) communities in the presence of daylight. Plants release a great portion of fixed carbon back to the atmosphere through autotrophic respiration. Along with the release of a substantial portion of newly fixed carbon through their roots, plant litters form a main source of energy for soil heterotrophs, including microorganisms and animals; this carbon pool is respired back to the atmosphere through heterotrophic respiration. A smaller amount of organic carbon remains unused and is stored in the soil. Some organic carbon is also used by some microorganisms for energy, but at a slower rate. CO_2 is also released into the atmosphere by anthropogenic activites such as fossil fuel burning (not shown). The methane (CH_4) cycle involves the conversion of organic residues (sugars) into CH_4 by methanogenesis, which is mainly carried out by a specialized group of archaea, called methanogens, under anoxic conditions. However, most CH_4 produced in soils is immediately oxidized by methanotrophs, which use CH_4 as a source of energy. This is mainly an aerobic process, and the availability of oxygen is a rate-limiting step. Methanotrophs also oxidize some atmospheric CH_4. The CO_2 produced by methane oxidation then enters into the CO_2 cycle (part a). c | The substrates for nitrous oxide (N_2O) production, ammonium (NH_4^+) and nitrate

(NO_3^-), enter soils in various forms. Atmospheric dinitrogen (N_2) can be deposited in the soil following fixation by soil microorganisms and is subsequently converted to NH_4^+; alternatively, reactive forms (mainly NO_3 and NH_3) can be deposited in precipitation or as dry deposition. Sources of N_2O, including fixed N_2, can also be released from organic residues from plants and animal waste and nitrogen fertilizers. The major source of anthropogenic substrate is agricultural application of nitrogen fertilizers and manure. In soil, a considerable amount of NH_4^+ is used by plants and microorganisms, and the remaining portion is transformed into NO_3^- by NH_3 oxidizing bacteria and archaea through nitrification. Most NO_3^- is converted into N_2 via various nitrogen oxides (including N_2O) by denitrification processes (carried out by denitrifying bacteria), and these then escape in the atmosphere. Some nitrate is leached into the groundwater, and some is used by plants.

7.5 MECHANISMS TO SOLVE CLIMATE CHANGE

Microbial processes have a central role in the global fluxes of the key biogenic greenhouse gases (carbon dioxide, methane and nitrous oxide) and are likely to respond rapidly to climate change. Microorganisms regulate terrestrial greenhouse gas flux. This involves consideration of the complex interactions that occur between microorganisms and other biotic and abiotic factors. The potential to mitigate climate change by reducing greenhouse gas emissions through managing terrestrial microbial processes is a tantalizing prospect for the future (Anisimov et al,1999)

7.5.1 Microbial Communities and Carbon Cycle

Microorganisms play key role in determining the longevity and stability of this carbon and whether or not it is released into the atmosphere as greenhouse gas which means mediate the processes of carbon cycle. Microorganisms are slow down global warming and implications for crucial ecological processes such as nutrient cycling which rely on microbial activity. Microorganisms are critical in the process of breaking down and transforming dead organic material into forms that can be reused by other organisms. This is why the microbial enzyme systems involved are viewed as key ‘engines’ that drive the Earth’s biogeochemical cycles. The terrestrial carbon cycle is dominated by the balance between photosynthesis and respiration. Carbon is transferred from the atmosphere to soil via ‘carbon-fixing’ autotrophic organisms such as photosynthesizing plants, photo and chemoautotrophic microorganisms these are synthesis atmospheric carbon dioxide in to organic material. Practically, microorganisms use carbon for their metabolism substrate due to these highly consume atmospheric carbon dioxide (Schlesinger & Lichter, 2001). Carbon Cycle is shown in Figure 7.2.

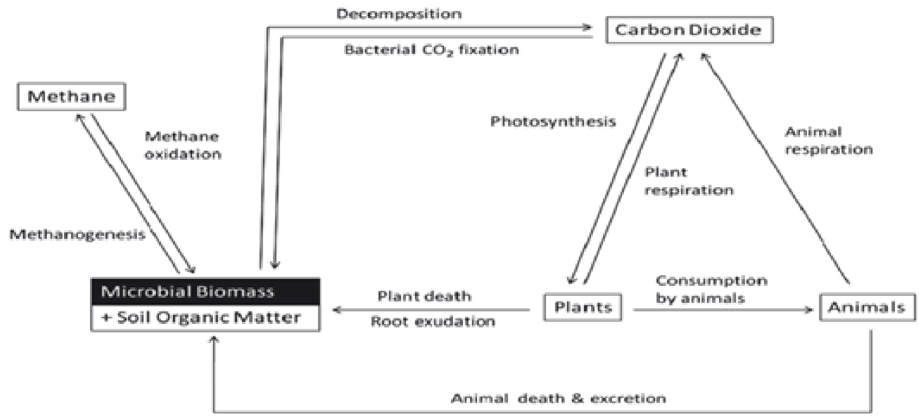

Figure7.2:carbon cycle (Source:Schlesinger & Lichter, 2001)

The cycling of carbon by variety of bacteria and fungi species occurs in aquatic habitats. Even relatively oxygen-free zones such as in the deep mud of lakes, ponds and other water bodies can be regions where the anaerobic conversion of carbon takes place. Both types of conversion take place in the presence and the absence of oxygen. Algal involvement is an aerobic process. In anaerobic environments, microorganisms can cycle the carbon compounds to yield energy in a process known as fermentation. Other microorganisms are able to participate in the cycling of carbon. For example, green and purple sulfur bacteria are able to use the energy they gain from the degradation of a compound called hydrogen sulfide to degrade carbon compounds (Benhelal, 2017). Other bacteria such as *Thiobacillus ferrooxidans* uses the energy gained from the removal of an electron from iron containing compounds to convert carbon. The anerobic degradation of carbon is done only by microorganisms. This degradation is a collaborative effort involving numerous bacteria such as *Bacteroides succinogene*s, *Clostridium butyricum*, and *Syntrophomonas sp*. This bacterial collaboration is termed interspecies hydrogen transfer and finally responsible for bulk of carbon dioxide and methane is released in to atmosphere (**Schlesinger & Lichter, 2001).**

7.5.2 Microbial Communities and Methane Cycle

Cycling of carbon between carbon dioxide and organic compounds are considered as ecologically significant. Both eukaryotes (plants and algae) and autotrophic bacteria (cyanobacteria) are contribute a great significance role in the fixation of carbon dioxide into organic compounds. As well as consumers are used organic compounds and release carbon dioxide. Methane (CH_4) is a greenhouse gas most of the time enters to atmosphere because of microbial action. Methane consuming microorganisms are critical to maintaining a healthy climate on Earth (Bajracharya et al, 2015). Bacteria use methane for metabolism as energy source. Methanotrophic bacteria is consume methane as their only source of energy and convert it to carbon dioxide during their digestive process. These bacteria can consume huge concentration of methane which is helpful in reducing methane emission from methane producing factories and landfills. Microorganisms are used high amount of methane compounds which is found at everywhere.

In anaerobic conditions just like deep compacted mud, carbon dioxide easily changed in to methane this is accomplished by methanogenic bacteria. The conversion process needs hydrogen, yields water and energy for the methanogens. To accomplish the recycling pattern another group of methane bacteria called methaneoxidizing bacteria or methanotrophs (literally "methane eaters") can convert methane to carbon dioxide. This conversion, which is an aerobic process, also yields water and energy. In the presence of oxygen, CH_4 is oxidized to CO_2 by methanotrophic bacteria. The oxidation of CH_4 to CO_2 completes the carbon cycle. Methanotrophs tend to live at the boundary between aerobic and anaerobic environments. They have access to the methane produced by the anaerobic methanogenic bacteria, but also access to the oxygen needed for their conversion of the methane (Alexis, 2017).

7.5.3 Microbial Communities and Nitrogen Cycle

Nitrogen is existed in an elemental form. It is the major component of the air constituting about 78% of the gases in the earth atmosphere. There are also different nitrogen gaseous compounds that exist in the atmosphere including NH_3, NO and N_2O. Nitrogen is in the form of a very stable molecule (N_2) which is unusable by plants and animals without fixation. Nitrogen Fixation is the process of changing atmospheric nitrogen into chemical forms which is usable by living things (Staddon et al, 2004). N_2 enters in to biosphere via biological fixation. Biological nitrogen fixation will ever totally replace industrial fixation for intensive agriculture. Rhizobium bacteria which cause formation of nodules on the roots of legumes such as soybeans and alfalfa. The bacteria are fairly specific for certain plants for example, the species which infects soybeans will not infect alfalfa. The bacterium attaches to a root hair of the plant and in response the plant forms a hollow thread leading into the root. Bacteria grow through this infection thread and eventually initiate formation of a nodule on the root. As much as 30 percent of the weight of a nodule may be bacteria. The plant supplies energy and nutrients for bacteria; bacteria and fungus supply nitrogen from the air in a form the plant can use through fixation. This is an example of symbiotic nitrogen fixation. Specific bacteria (Rhizobium trifolium) possess nitrogeniase enzymes that can fix atmospheric nitrogen into a form (ammonium ion) that is chemically useful to higher organisms as part of the symbiotic relationship, the plant convert the 'fixed' ammonium ion to nitrogen oxides and amino acids to form proteins and other molecules like alkaloids (Berman-Frank et al, 2003). Nitrogen Cycle is shown in Figure 7.3.

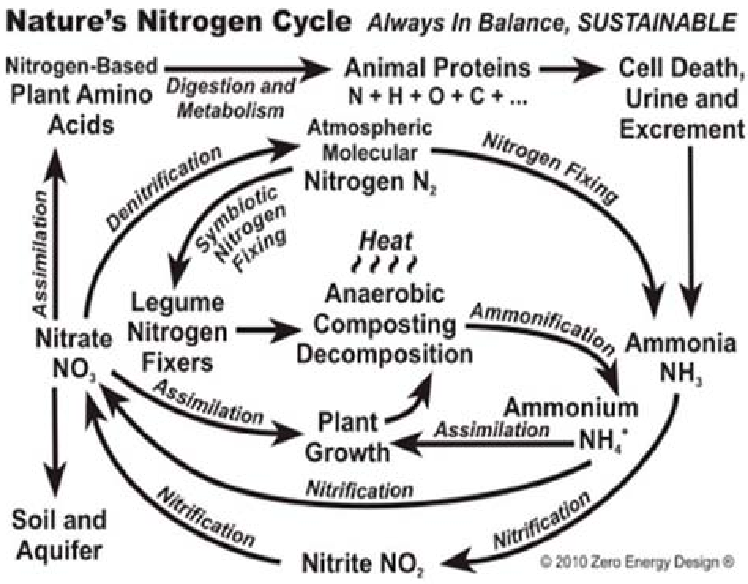

Figure 7.3. Nitrogen Cycle (Source:Berman-Frank et al, 2003)

7.6 HOW ARE MICROBES CONTRIBUTING TO GLOBAL WARMING?

A group of animals called the ruminants such as sheep, cattle, goats, camels and water buffalo have a special four chambered stomach. The largest compartment is called the rumen. This pouch is teeming with billions of bacteria, protozoa, moulds and yeasts. These microbes digest the cellulose found in the grass, hay and grain that the animal consumes, breaking it down into simpler substances that the animal is able to absorb. Cellulose is the tough insoluble fibre that makes up the cell walls of plants; it gives the plant structure.

Animals can't break down cellulose directly as they don't produce the necessary digestive enzymes. The methanogens, a group of archaea that live in the rumen, specialise in breaking down the animal's food into the gas methane. The ruminant then belches this gas out at both ends of its digestive system. Methane is a very powerful greenhouse gas because it traps about 20 times as much heat as the same volume of carbon dioxide. As a result, it warms the planet up to 20 times more than carbon dioxide. Around 20% of global methane production is from farm animals.

Scientists are looking at ways to reduce the amount of methane emissions from ruminants. One group in Australia has developed a vaccine which can be given to the animal. The vaccine works by preventing the microbes that live in the animals' rumen from producing methane. The vaccine was tested on sheep which belched 8% less methane in a 13-hour test.

At present the vaccine is only effective against 20% of the microbial species that produce methane. To reduce methane production further scientists, need to produce a vaccine that is active against more of the archaea that produce methane (Bartdorff et al, 2008).

The scientists were concerned that stopping the methanogens from working might affect the digestion of the ruminants and result in the animal being smaller. However, what they did find is that cutting down the amount of methane an animal produces actually boosts its growth. This is because the process of methanogenesis uses energy which can result in a small but significant loss of energy available to an animal. Another group of researchers is looking to see if adding certain food additives to the diet of

Genome: It is a map of the complete genetic make-up of an organism. The basic units of genetic information are called genes. The genome, which is made up of genes, contains all of the biological information needed to build and maintain a living example of that organism.

Check Your Progress 1

Note: a) Use the space given below for your answers.

b) Check your answers with those given at the end of the unit

1. What is climate Change?

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2. What are different Sources of Greenhouse Gases?

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3. What are important causes of global warming?

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7.7 GREENHOUSE GASES IN SOIL

The role of soil microbes in climate change

- Soil is not a sterile substance. It is home to a vast array of life ranging from moles to microbes which makes it a very active substance. As the climate heats up it is predicted that the activity of microbes responsible for the breakdown of carbon-based materials in the soil will speed up. If this happens then even more carbon dioxide will be released into the environment. This is because increased microbial activity results in an increase in respiration, which produces more carbon dioxide as a waste product.

- Group of microorganisms called denitrifying bacteria convert nitrous oxide into harmless nitrogen gas. other groups of microorganisms, all of which consume nitrous oxide and potentially mitigate emissions.
- Prochlorococcus and Synechococcus are single-celled cyanobacteria. They are the smallest yet most abundant photosynthetic microbes in the ocean. Researchers esti-mate that Prochlorococcus and Synechococcus remove about 10 billion tons of carbon from the air each year; this is about two-third of the total carbon fixation that occurs in the oceans.
- Microbial power could slow down increases in levels of carbon di-oxide and other greenhouse gases and eventually reduce global climate change. The researchers screened available microbial genomes encoding the enzyme systems that catalyze the reduction of the nitrous oxide to harmless nitrogen gas. They discovered an unexpected broad distribution of this class of enzymes across different groups of microbes with the power to transform nitrous oxide to innocuous nitrogen gas.
- Methylobacillus is a group of methylotrophic anaerobic bacteria, found in large numbers in marine and fresh wa-ter ecosystems. These organisms are one of earth's most important carbon recycler, and they recycle carbon com-pounds as methane, methanol and methylated amines. In general, methylotrophs can use green-house gases such as carbon dioxide and methane as substrates to fulfill their energy and carbon needs.
- Microbes that convert carbon dioxide, a green-house gas, into calcium carbonate. When the bacteria are used as an enzyme, it has been found to transform CO_2 into calcium carbonate ($CaCO_3$)(Bardgett et al, 2008)

7.8 REDUCTION OF CO2 USING PHOTOSYNTHETIC CYANOBACTERIA

- Most types of photosynthetic bacteria derive energy from ATP, which helps in the conversion of CO_2 to biomass and other products.
- Cyanobacteria are capable of fixing atmospheric nitrogen and carbon. Similar to algae, they are distinct and broadly distributed and exist as biofilms or as suspended planktonic cells.
- cyanobacteria played a decisive role in atmospheric formation by decreasing CO_2 concentration and increasing oxygen.
- cyanobacteria are the most efficient in atmospheric carbon utilization over algae,cyanobacteria are found to be a key player by accounting for 20~30% of Earth's photosynthetic activity (Drigo et al, 2004).

7.9 COMBATING GLOBAL WARMING THROUGH BIOFUELS

- Genetically modified it to overproduce the cellulase enzyme that is capable of converting the cellulose and hemicellulose into ethanol. The remaining lignin by-product can be burned to produce energy.
- The plant material used is the edible part of the plant such as sugar cane and sugar beet or corn kernels because it can be easily being broken down to sugar (glucose). The sugar can then be fermented (broken down) to ethanol by mi-crobes such as the yeast Saccharomyces cerevisiae.
- The scientists are also trying to identify and isolate the genes from wood termites that control cellulase enzyme along with the genes responsible for the breakdown of sugar into ethanol and transfer them into another bacte-rium that can be easily cultivated in the laboratory. This genetically modified bacterium, with its new set of genes, will be able to produce biofuel from cellulose.
- The fungus is genetically modified to produce large quantities of cellulase. A staggering 75% of the straw fibre is converted into sugar. The left over woody matter, lignin, is dried and then pressed into burnable cakes. The glucose is then fermented with yeast to produce the biofuel ethanol.
- So microbes could be the key to the future of powering cars in an eco-friendly way with cellulose ethanol and Combating Global Warming Through Biofuels (Drigo et al, 2004).

7.10 MICROBES AND GLOBAL WARMING

Most studies to date on the effects of climate change on biological systems and soil microbes have examined single factors, such as elevated atmospheric CO2 concentration, warming, or drought. However, there is considerable potential for interactions between these factors to have additive or antagonistic effects on soil microorganisms and their activities related to greenhouse gas production. Very little is known about the effects of multiple and interacting climate drivers on soil microbes and their contribution to climate change, and, being so complex, they are likely to be very difficult, if not impossible to predict.

Soil microbial communities and their activities to combined effects of elevated temperature and atmospheric CO_2, the combined and positive effect of elevated temperature and atmospheric CO_2on microbial decomposition of peat was found to be greater than when these factors operated alone creating an even stronger positive feedback on carbon loss from soil as DOC and respiration.

Diversity of different components of the soil microbial community, including bacteria, saprophytic fungi and mycorrhizal fungi are also affected directly and indirectly by climate change.

7.11 MICROBES AS CARBON SINK

A group of oceanic micro-organisms play a vital role in the fight against climate change and the role of oceans in absorbing carbon dioxide is crucial to understand. There is a lot of carbon floating in the oceans that is known as refractory dissolved organic matter and it has been put there by a hitherto little-regarded group of creatures called aerobic anoxygenic photoheterotrophic bacteria (AAPB).

A whole new "sink" for carbon dioxide is atmosphere.The main way that carbon dioxide is absorbed by the ocean is through photosynthesis by planktonic algae. These algae are the basis of most food chains in the sea that are being eaten by tiny animals that are, in turn, eaten by larger ones. After the death of these creatures, their remains sink to the sea floor, where some are eaten and some are buried indefinitely. These remains are known in the jargon as particulate organic matter. The dead creatures contain some of the organic com-pounds that dissolve out of them and into the water.This dissolved organic matter was not thought to be an important component of the total carbon dioxide

7.12 INDUSTRIAL EFFLUENT AND LAND FILL LEACHATE

Methane (CH4), a potent greenhouse gas (GHG) with a global warming potential (GWP) ~23 times higher than that of carbon dioxide (CO_2) is produced by Landfills. There is urgent need to prevent methane emissions from large landfills. Methanotrophs are a group of bacteria that consume methane. In cover soil methanotrophs prevent fugitive methane emissions. In present scenario two general research techniques are performed to prevent methane emissions. First, a dimensionless number method developed based on Michaelis-Menten kinetics. Second, effects of nutrient amendments on methane oxidation and nitrous oxide production were examined by constructing soil microcosms using landfill cover soils. Mehanotrophic activity and community structure can be differentially affected by both landfill gas composition and amendments thus provide insights for best manipulation of methanotrophic processes to better mitigation of GHG emission.

7.13 WHAT IS SEQUESTRATION OF GREENHOUSE GASES?

Carbon dioxide is the most commonly produced greenhouse gas. Carbon sequestration is the process of capturing and storing atmospheric carbon dioxide. It is one method of reducing the amount of carbon dioxide in the atmosphere with the goal of reducing global climate change.

7.14 FOREST AND OCEAN, SEQUESTRATION OF GREENHOUSE GASES

Forests are important carbon pools which continuously exchange CO_2 with the atmosphere, due to both natural processes and human action. Understanding forests' participation in the greenhouse effect requires a better understanding of the carbon cycle at the forest level.

7.14.1 The Role of Forests in Climate Change

Organic matter contains carbon susceptible to be oxidized and returned to the atmosphere in the form of CO2. Carbon is found in several pools in the forest.

The vegetation: living plant biomass consisting of wood and non-wood materials. Although the exposed part of the plant is the most visible, the below-ground biomass (the root system) must also be considered. The amount of carbon in the biomass varies from between 35 to 65 percent of the dry weight (50 percent is often taken as a default value). Dead wood and litter: dead plant biomass, made up of plant debris. Litter in particular is an important source of nutrients for plant growth (Morgan, 2002). (Figure 7.4)

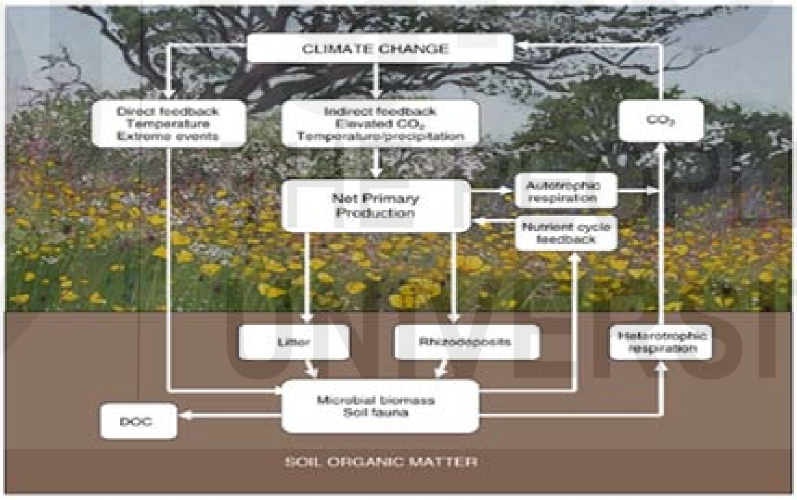

Figure7.4: Flow chart for Carbon Sequestration (Source: Morgan, 2002)

Soil organic matter, the humus. Humus originates from litter decomposition. Organic soil carbon represents an extremely important pool. At the global level, 19 percent of the carbon in the earth's biosphere is stored in plants, and 81 percent in the soil. In all forests, tropical, temperate and boreal together, approximately 31 percent of the carbon is stored in the biomass and 69 percent in the soil. In tropical forests, approximately 50 percent of the carbon is stored in the biomass and 50 percent in the soil (IPCC, 2007).

The process of photosynthesis explains why forests function as CO_2 sinks, removing CO_2 from the atmosphere. Atmospheric CO_2 is fixed in the plant's chlorophyll parts and the carbon is integrated to complex organic molecules which are then used by the whole plant. (Figure 7.5)

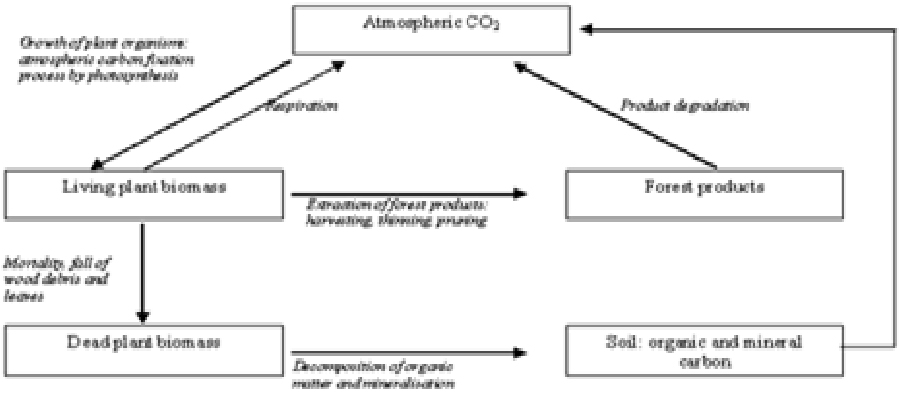

Figure 7.5: Carbon Sequestration (Source: Morgan, 2002)

7.14.2 Ocean, Sequestration of Greenhouse Gases

Oceans absorb roughly 25 percent of carbon dioxide emitted from human activities annually. Carbon goes in both directions in the ocean. Colder and nutrient rich parts of the ocean are able to absorb more carbon dioxide than warmer parts. Therefore, the polar regions typically serve as carbon sinks. By 2100, much of the global ocean is expected to be a large sink of carbon dioxide, potentially altering the ocean chemistry and lowering the pH of the water, making it more acidic.

The capacity of oceans sequestration of CO2 worldwide lies in between 1400 and 20,000 Gt of CO2 which is the highest among other sedimentary basins. When CO2 is stored into the ocean, the dissolved CO2 can react with the oceanic water and form carbonic acid which will increase the acidity of the oceanic water and decrease in pH.

7.15 TRANSFORMATION OF GREENHOUSE GASES

Greenhouse gases such as methane and carbon dioxide are emitted from landfills, as well as from agricultural facilities due to concentrated animal waste, contributing to climate change. Safe and environmentally sound disposal of animal wastes is a major challenge for larger scale agricultural producers. Using fossil fuels for energy contributes to global warming, and energy needs are growing in many countries. Capturing waste gases and converting them to energy can help to mitigate climate change by lowering consumption of fossil fuels, at the same time reducing the release of harmful gases. According to the United Nations Environment Programme (UNEP), in order to ensure the average global temperature does not rise by more than 2°C by 2020, the percentage of primary energy that is produced from non-fossil fuel energy sources, such as biogas, will need to increase by as much as 28% by 2020.

7.16 CO2 SEQUESTRATION/ASSIMILATION USING ALGAE

CO_2 mitigation with algae is found to be a sustainable process with simultaneous generation of high calorific products, such as biodiesel, pigments, fatty acids, etc. The potential utilization of algae is mainly attributed to its wide distribution, high biomass production, capability to adjust in adverse conditions, swift carbon uptake and utilization. Both macro and micro algae have the capability to metabolize inorganic carbon by a photoautotrophic mechanism using carbonic anhydrase enzyme (CAE). The generated $NADH_2$ from the electron transport chain combines with the RuBisCo (Ribulose- 1,5-bisphosphate carboxylase/oxygenase, provided by CAE) and helps in carbohydrate generation from CO_2 and provides the reducing power in the Calvin cycle for glucose synthesis (Green et al,2004). (Figure 7.7)

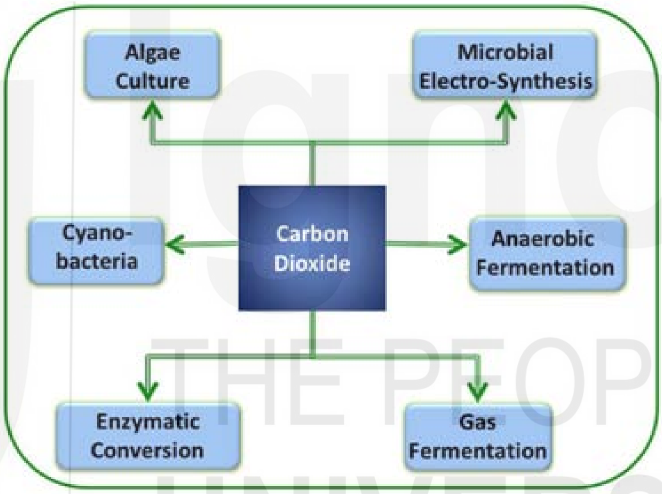

Figure 7.7:Various biological processes that have potential for CO_2 sequestration along with sustainable bioenergy/chemical production. (Source: Green et al, 2004)

7.17 OCEAN CARBON ABSORPTION

When carbon-dioxide-rich air meets seawater containing less carbon dioxide, the greenhouse gas diffuses from the atmosphere into the ocean. Today, about a quarter of human-produced carbon dioxide emissions get absorbed into the ocean. Once the carbon is in the water, it can stay there for hundreds of years.

Warm, CO_2-rich surface water flows in ocean currents to colder parts of the globe, releasing its heat along the way. In the polar regions, the now-cool water sinks several miles deep, carrying its carbon burden to the depths. Eventually, that same water wells up far away and returns carbon to the surface; but the entire trip is thought to take about a thousand years. In other words, water upwelling today dates from the Middle Ages – long before fossil fuel emissions.

That's good for the atmosphere, but the ocean pays a heavy price for absorbing so much carbon: acidification. Carbon dioxide reacts chemically with seawater to make the water more acidic. This fundamental change threatens many marine creatures. The chain of chemical reactions ends up reducing the amount of a particular form of carbon the carbonate ion that these organisms need to make shells and skeletons. Dubbed the "other carbon dioxide problem," ocean acidification has potential impacts on millions of people who depend on the ocean for food and resources.

Check Your Progress 2

Note: a) Use the space given below for your answers.

b) Check your answers with those given at the end of the unit

1. Explain the role of soil microbes in climate change.

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2. What is Sequestration of Greenhouse Gases?

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3. Explain Reduction of CO2 Using Photosynthetic Cyanobacteria?

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7.18 LET US SUM UP

We have studied the Climate change. We have studied the climate change mitigation by microorganisms and sequestration of carbon by natural resources. We have studied the enzymes required for mitigation of greenhouse Gases.

7.19 KEY WORDS

Global warming: Global warming is the long-term warming of the planet's overall temperature. Though this warming trend has been going on for a long time, its pace has significantly increased in the last hundred years due to the burning of fossil fuels.

Pollution: Pollution is the introduction of harmful materials into the environment. These harmful materials are called pollutants.

Greenhouse gas: A gas that absorbs and emits radiant energy within the thermal infrared range, causing the greenhouse effect. The primary greenhouse gases in Earth's atmosphere are water vapour (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and ozone (O_3).

Methanotrophs: Methanotrophs are prokaryotes that metabolize methane as their source of carbon and chemical energy. They are bacteria or archaea, can grow aerobically or anaerobically, and require single-carbon compounds to survive.

Enzyme: Enzymes are proteins that help speed up metabolism, or the chemical reactions in our bodies. They build some substances and break others down. All living things have enzymes.

Fungi:A fungus (plural: fungi or funguses) is any member of the group of eukaryotic organisms that includes microorganisms such as yeasts and molds, as well as the more familiar mushrooms.

Bacteria: Bacteria are small single-celled organisms. Bacteria are found almost everywhere on Earth and are vital to the planet's ecosystems.

Biofuel:"liquid, solid, or gaseous fuel produced by conversion of biomass such as bioethanol from sugar cane or corn, charcoal or woodchips, and biogas from anaerobic decomposition of wastes"

7.20 SUGGESTED FURTHER READING/REFERENCES

- Alexis Bazzanella, D. K. (2017). Technologies for Sustainability and Climate Protection –Chemical Processes and Use of CO2. Available online at: https:// dechema.de/en/energyandclimate_CO_2_Buch_engl.pdf (accessed February 15, 2020).
- Anisimov OA, Nelson FE, Pavlov AV. Predictive scenarios of permafrost development under condi-tions of global climate change in the XXI century. Earth Cryology. 1999; 3: 15-25.
- Bajracharya, S., Ter Heijne, A., Dominguez Benetton, X., Vanbroekhoven, K., Buisman, C. J. N., Strik, D. P. B. T. B., et al. (2015). Carbon dioxide reduction by mixed and pure cultures in microbial electro synthesis using an assembly of graphite felt and stainless steel as a cathode. Bioresour. Technol. 195, 14–24. doi: 10.1016/j.biortech.2015.05.081

- Bardgett, R. D., Freeman, C. & Ostle, N. J. Microbial contributions to climate change through carbon cycle feedbacks. ISME J. 2, 2805–2814 (2008). This paper highlights the central role of soil microorganisms in land–atmosphere carbon exchange and its consequences for climate change.
- Bartdorff, O. Wallmann, K., Latif, M. and Semenov, V. Phanerozoic evolution of atmospheric methane. Global Biogeochem. Cycles 22, GB1008 (2008).
- Benhelal, E., Zahedi, G., Shamsaei, E., and Bahadori, A. (2013). Global strategies and potentials to curb CO2 emissions in cement industry. J. Clean. Prod. 51, 142–161. doi: 10.1016/j.jclepro.2012.10.049
- Berman-Frank, I., Lundgren, P., and Falkowski, P. (2003). Nitrogen fixation and photosynthetic oxygen evolution in cyanobacteria.Res. Microbiol. 154, 157–164. doi: 10.1016/S0923-2508(03) 00029-9
- Briones MJI, Poskitt J, Ostle N. Influence of warming and enchytraeid activities on soil CO_2 and CH_4 fluxes. Soil Biol. Biochem. 2004; 36: 1851-1859.
- Drigo, B., Kowalchuk, G. A. & van Veen, J. A. Climate change goes underground: effects of elevated atmospheric CO2 on microbial community structure and activities in the rhizosphere. Biol. Fertil. Soils 44, 667–679 (2008)
- Green, J. L. et al. Spatial scaling of microbial eukaryote diversity. Nature 432, 747–750 (2004).
- IPCC. 2007. Climate Change 2007: Synthesis Re-port. Available at <http://www.ipcc.ch/publications_and_data/publications _ipcc_ fourth_assessment_report _synthesis_report.htm>.
- Jenkinson DS, Adams DE, Wild A. Model estimates of CO_2 emissions from soil in response to global warming. Nature, 1991; 351: 304–306.
- Melillo JM, Steudler PA, Aber JD, Newkirk K, Lux H, Bowles FP, Catricala C, Magill A, Ahrens T, Morrisseau S. Soil Warming and Carbon-Cycle Feedbacks to the Climate System, Science, 2002; 298: 2173-2176.
- Morgan, J. A. Looking beneath the surface. Science 298, 1903–1904 (2002).
- Panikov NS. Understanding and prediction of soil microbial community dynamics under global change. Appl. Soil Ecol. 1999; 11: 161-176.
- Sanford RA, Wagner DD, Cu QW, Chee-Sanford J, Thomas SH, Cruz-Garcia C, Rodriguez G, Mas-sol-Deya A, Krishnani KK, Ritalahti KM, Nissen S, Konstantinidis KT, Loffler FE. Unexpected non-denitrifier nitrous oxide reductase gene diversity and abundance in soils. Proceed. Natl. Acad. Sc. 2012; 109(48): 19709-19714. DOI: 10.1073/ pnas.1211238109

- Schlesinger WH, Lichter J. Limited carbon storage in soil and litter of experimental forest plots under in-creased CO_2. Nature. 2001; 411: 466-469.
- Staddon, P. L., Jakobsen, I. & Blum, H. Nitrogen input mediates the effect of free-air CO2 enrichment on mycorrhizal fungal abundance. Glob. Chang. Biol. 10, 1678–1688 (2004).
- Willey JM, Sherwood LM, Woolverton CJ. Pres-cott's Principles of Microbiology, McGraw-Hill, New York, 2009.

7.21 ANSWERS TO CHECK YOUR PROGRESS

Check Your Progress 1

1. Climate change refers to long-term shifts in temperatures and weather patterns. These shifts may be natural, such as through variations in the solar cycle. But since the 1800s, human activities have been the main driver of climate change, primarily due to burning fossil fuels like coal, oil and gas. Burning fossil fuels generates greenhouse gas emissions that act like a blanket wrapped around the Earth, trapping the sun's heat and raising temperatures.

   Climate change describes a change in the average conditions — such as temperature and rainfall — in a region over a long period of time. For example, 20,000 years ago, much of the United States was covered in glaciers. In the United States today, we have a warmer climate and fewer glaciers.

   Global climate change refers to the average long-term changes over the entire Earth. These include warming temperatures and changes in precipitation, as well as the effects of Earth's warming, such as:

   - Rising sea levels
   - Shrinking mountain glaciers
   - Ice melting at a faster rate than usual in Greenland, Antarctica and the Arctic
   - Changes in flower and plant blooming times.

2. **Different sources of Greenhouse Gases:**Greenhouse gases trap heat and make the planet warmer. Human activities are responsible for almost all of the increase in greenhouse gases in the atmosphere over the last 150 years.The three most important greenhouse gases are carbon dioxide, methane and nitrous oxide and these have increased dramatically in recent years due to human activity.

   GHG that are emitted as a result of human activity:

   carbon dioxide (CO_2), which comes from Industries, Thermal power plants, Transportation and fossil fuels combustion.

   Methane (CH_4), which comes from landfills, coal mines, agriculture, and oil and natural gas operations

Nitrous oxide (N_2O), which comes from using nitrogen fertilizers and certain industrial and waste management processes and burning fossil fuels

High global warming potential (GWP) gases, which are human-made industrial gases

Hydrofluorocarbons (HFCs)

Perfluorocarbons (PFCs)

Sulfur hexafluoride (SF6)

Nitrogen trifluoride (NF3)

3. Global warming occurs when carbon dioxide (CO_2) and other air pollutants collect in the atmosphere and absorb sunlight and solar radiation that have bounced off the earth's surface. Normally this radiation would escape into space, but these pollutants, which can last for years to centuries in the atmosphere, trap the heat and cause the planet to get hotter. These heat-trapping pollutants—specifically carbon dioxide, methane, nitrous oxide, water vapor, and synthetic fluorinated gases—are known as greenhouse gases, and their impact is called the greenhouse effect.

Causes for rising emissions

Burning coal, oil and gas produces carbon dioxide and nitrous oxide.

Cutting down forests (deforestation)

Increasing livestock farming.

Fertilisers containing nitrogen produce nitrous oxide emissions.

Fluorinated gases are emitted from equipment and products that use these gases.

Check Your Progress 2

1. The role of soil microbes in climate change

- Soil is not a sterile substance. It is home to a vast array of life ranging from moles to microbes which makes it a very active substance. As the climate heats up it is predicted that the activity of microbes responsible for the breakdown of carbon-based materials in the soil will speed up. If this happens then even more carbon dioxide will be released into the environment. This is because increased microbial activity results in an increase in respiration, which produces more carbon dioxide as a waste product.
- Group of microorganisms called denitrifying bacteria convert nitrous oxide into harmless nitrogen gas. other groups of microorganisms, all of which consume nitrous oxide and potentially mitigate emissions.
- Prochlorococcus and Synechococcus are single-celled cyanobacteria.

They are the smallest yet most abundant photosynthetic microbes in the ocean. Researchers esti-mate that Prochlorococcus and Synechococcus remove about 10 billion tons of carbon from the air each year; this is about two-third of the total carbon fixation that occurs in the oceans.

- Microbial power could slow down increases in levels of carbon di-oxide and other greenhouse gases and eventually reduce global climate change. The researchers screened available microbial genomes encoding the enzyme systems that catalyze the reduction of the nitrous oxide to harmless nitrogen gas. They discovered an unexpected broad distribution of this class of enzymes across different groups of microbes with the power to transform nitrous oxide to innocuous nitrogen gas.
- Methylobacillus is a group of methylotrophic anaerobic bacteria, found in large numbers in marine and fresh wa-ter ecosystems. These organisms are one of earth's most important carbon recycler, and they recycle carbon com-pounds as methane, methanol and methylated amines. In general, methylotrophs can use green-house gases such as carbon dioxide and methane as substrates to fulfill their energy and carbon needs.
- Microbes that convert carbon dioxide, a green-house gas, into calcium carbonate. When the bacteria are used as an enzyme, it has been found to transform CO_2 into calcium carbonate ($CaCO_3$).

2. **Sequestration of Greenhouse Gases:** Carbon dioxide is the most commonly produced greenhouse gas. Carbon sequestration is the process of capturing and storing atmospheric carbon dioxide. It is one method of reducing the amount of carbon dioxide in the atmosphere with the goal of reducing global climate change.

   Biological carbon sequestration is the storage of carbon dioxide in vegetation such as grasslands or forests, as well as in soils and oceans.

- Oceans absorb roughly 25 percent of carbon dioxide emitted from human activities annually. Carbon goes in both directions in the ocean. When carbon dioxide releases into the atmosphere from the ocean, it creates what is called a positive atmospheric flux. A negative flux refers to the ocean absorbing carbon dioxide. Think of these fluxes as an inhale and an exhale, where the net effect of these opposing directions determines the overall effect. Colder and nutrient rich parts of the ocean are able to absorb more carbon dioxide than warmer parts. Therefore, the polar regions typically serve as carbon sinks. By 2100, much of the global ocean is expected to be a large sink of carbon dioxide, potentially altering the ocean chemistry and lowering the pH of the water, making it more acidic.
- Carbon is sequestered in soil by plants through photosynthesis and can be stored as soil organic carbon (SOC). Agroecosystems can degrade and deplete the SOC levels but this carbon deficit opens up the opportunity to store carbon through new land management practices. Soil can also store

carbon as carbonates. Such carbonates are created over thousands of years when carbon dioxide dissolves in water and percolates the soil, combining with calcium and magnesium minerals, forming "caliche" in desert and arid soil.

- Carbonates are inorganic and have the ability to store carbon for more than 70,000 years, while soil organic matter typically stores carbon for several decades. Scientists are working on ways to accelerate the carbonate forming process by adding finely crushed silicates to the soil in order to store carbon for longer periods of time.
- About 25 percent of global carbon emissions are captured by plant-rich landscapes such as forests, grasslands and rangelands. When leaves and branches fall off plants or when plants die, the carbon stored either releases into the atmosphere or is transferred into the soil. Wildfires and human activities like deforestation can contribute to the diminishment of forests as a carbon sink.
- While forests are commonly credited as important carbon sinks, California's majestic green giants are serving more as carbon sources due to rising temperatures and impact of drought and wildfires in recent years. Grasslands and rangelands are more reliable than forests in modern-day California mainly because they don't get hit as hard as forests by droughts and wildfires, according to research from the University of California, Davis. Unlike trees, grasslands sequester most of their carbon underground. When they burn, the carbon stays fixed in the roots and soil instead of in leaves and woody biomass. Forests have the ability to store more carbon, but in unstable conditions due to climate change, grasslands stand more resilient.

3. Reduction of CO_2 Using Photosynthetic Cyanobacteria

- Most types of photosynthetic bacteria derive energy from ATP, which helps in the conversion of CO_2 to biomass and other products.
- Cyanobacteria are capable of fixing atmospheric nitrogen and carbon. Similar to algae, they are distinct and broadly distributed and exist as biofilms or as suspended planktonic cells.
- cyanobacteria played a decisive role in atmospheric formation by decreasing CO_2 concentration and increasing oxygen.
- cyanobacteria are the most efficient in atmospheric carbon utilization over algae, cyanobacteria are found to be a key player by accounting for 20~30% of Earth's photosynthetic activity.