**Water logged soils**

On water logged soils the plants suffer from oxygen deficiencies due to an-aerobic conditions. This results in the built up of CO2, ethylene and other potentially toxic gases in the soli. This also results in failure of crops growth.

**Physical and chemical properties of water logged soils.**

**Temperature fluctuation**

The water logged soils tend to show different temperature fluctuation than the dry soil. Day temperature tends to be lower and night temperature is higher in water logged as compared to the normal soils. of this, there may be a pronounced effect on growth and metabolism of roots and soil micro flora.

**Localized area of atmospheric stress**

Localized anaerobic zone may develop during water logging .This may result in poor growth of root due to diffusible products of an aerobes and these substances ma be toxic to micro flora.

**Gas exchange in water logged soils**

The movement of respiratory gases within in the plants directional exchange with the atmosphere are greatly influenced by the environmental conditions within the soil and aerial environment. Oxygen may enter the plants in number of ways.

In non aquatic species, O2 & CO2 enter and leave the plant directly through the stomata and lenticels. Plants in unsaturated are greatly exposed to the O2 rich environment over most of there shoots and root surface , most of the gases exchange occurs by simple planar or radial movement , Where the O2 requirement of the roots are met largely by diffusion transport from the soil atmosphere . So in such cases there is very limited longitudinal movement of gas within the plants.

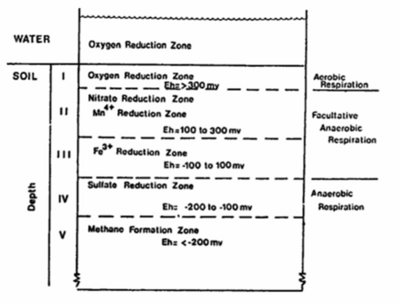
In water logged soils, the mode of gas exchange is very different because little or no O2 is available for radial entry to the roots, longitudinal movement between the root and shoot is the primary mode of gas transport. Longitudinal transport occurs in both the intercellular gas spaces and the stele (xylem vascular bundle). Radial movement tends to be bidirectional i.e. from root cortex to stele and to the soil. The later radial O2 loss is believed to be very important for survival of the plants in water logged soils. Oxygen may also enter in the plants in combined form as water.

In xylem, water is transported from root to shoot where O2 is ultimately released within the chloroplast during photosynthesis.

In submerged aquatic plants, the permeability of the leaves surface is high enough to permit gas exchange by liquid phase movement across the epidermal layer

In yellow water lily, the network of internal gas spaces serves as a pressurized flow through system which forces O2 down from the petioles of the young newly emerged leaves to the roots and rhizomes buried in the anaerobic sediments. Simultaneously ,CO2 is forced from the rhizomes up o the petioles of the older leaves where it is fixed by photosynthesis or released into the atmosphere. This type of ventilation also removes appreciable quantities of methane from the lake sediments.

**Redox potential in water logged soils:**

**[](http://microbewiki.kenyon.edu/index.php/File:Flooded_soil.png)**

[http://microbewiki.kenyon.edu/skins/common/images/magnify-clip.png](http://microbewiki.kenyon.edu/index.php/File:Flooded_soil.png)

schematic presentation of flooded soil from[Y.Chen and Y Avnimelech](http://microbewiki.kenyon.edu/index.php?title=Y.Chen_and_Y_Avnimelech&action=edit&redlink=1)

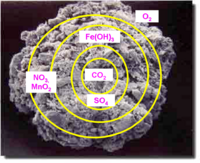
**Flooded soils** occur with complete water saturation of soil pores, and generally result in anoxic conditions of the soil environment. Flooded soil environments may include such [ecosystem](http://microbewiki.kenyon.edu/index.php?title=Wikipedia:ecosystem&action=edit&redlink=1) as: rice paddies; wetlands (swamps, marshes, and bogs); compacted soils; and post-rain soils (Scow, 2008). Additionally, similar redox conditions (where oxygen is lacking) can also be found within soil aggregates and along pollutant plumes, and thus many of the concepts discussed in this section may be applied to those environments.

Oxygen is only sparingly soluble in water and diffuses much more slowly through water than through air (Schlesinger, 1997). What little oxygen that is present in saturated soils in the form of dissolved O2 is quickly consumed through metabolic processes. Oxygen is used as terminal electron acceptor via respiration by roots, soil microbes, and soil organisms (Sylvia, 2005), and is lost from the soil system in the form of carbon dioxide (CO2). Heterotrophic respiration may completely deplete oxygen in flooded soils; and these effects may be observed within only a few millimeters of the soil surface (Schlesinger, 1997).

Due to the deficiency of oxygen in flooded soils, those organisms inhabiting flooded soils must be able to survive with little to no oxygen. Although energy yields are much greater with oxygen than with any other terminal electron acceptor (see [#Electron tower](http://microbewiki.kenyon.edu/index.php/Flooded_soils#Electron_tower) theory, section 2.1.1), under anoxic conditions anaerobic and facultative microbes can use alternative electron acceptors such as nitrate, ferric iron (Fe III), manganese (IV) oxide, sulfate, and carbon dioxide to produce energy and build biomass.

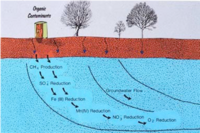
Microbial transformations of elements in anaerobic soils play a large role in biogeochemical cycling of nutrients and in greenhouse gas emissions. Changes in the oxidation state of terminal electron acceptors may result in nutrient loss from the system via volatilization or leaching. Anaerobic microbial processes including denitrification, methanogenesis, and methanotrophy are responsible for releasing greenhouse gases (N2O, CH4, CO2) into the atmosphere (Schlesinger, 1997).

Processes

[](http://microbewiki.kenyon.edu/index.php/File:Phenomenon_in_aggregates.png)

[http://microbewiki.kenyon.edu/skins/common/images/magnify-clip.png](http://microbewiki.kenyon.edu/index.php/File:Phenomenon_in_aggregates.png)

Electron acceptor used in aggregates. adjusted from [Prof. Kate lec #5](http://microbewiki.kenyon.edu/index.php?title=Prof._Kate_lec&action=edit&redlink=1)

[](http://microbewiki.kenyon.edu/index.php/File:Phenomena_in_pollutant_plume.png)

[http://microbewiki.kenyon.edu/skins/common/images/magnify-clip.png](http://microbewiki.kenyon.edu/index.php/File:Phenomena_in_pollutant_plume.png)

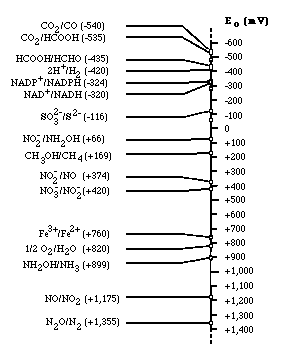
Order of electron acceptor in pollutant plume from [USGS](http://microbewiki.kenyon.edu/index.php?title=USGS&action=edit&redlink=1)

In general, flooded soils occur due to seasonal flooding or agricultural activity. Flooded soils can be often converted into non-flooded soils by the water level fluctuation and drainage. Through this variation of soil conditions, various gases are emitted into the atmosphere and environmental factors, such as redox potential (Eh), pH, acidity, alkalinity, and salinity, are continuously changing. As explained in the [introduction](http://microbewiki.kenyon.edu/index.php/Flooded_soils#Introduction), microorganisms can use alternative terminal electron acceptors (such as nitrate, perchlorate, sulfate, and carbon dioxide) when dissolved oxygen is absent. Microbes will successively use electron acceptors according to the order of energy yields resulting from electron acceptor utilization indicted on the electron tower (see [#Electron Tower](http://microbewiki.kenyon.edu/index.php/Flooded_soils#Electron_Tower) theory). The progression of electron acceptor utilization may also be observed in soil aggregates and pollutant plumes.

[**Oxidation/Reduction (Redox) Reaction**](http://en.wikipedia.org/wiki/Redox)

In redox reactions, one molecule (the reducing agent) loses electrons and another molecule (the oxidizing agent) accepts electrons. A classic example well known in the process of cellular respiration is when glucose (the reducing agent) reacts with oxygen (the oxidizing agent)and is oxidized to carbon dioxide. In this reaction, oxygen is reduced to water. Oxygen is the most common and highest energy yielding electron acceptor, and some organisms (strict aerobes) can not live long without it.(6) In flooded soils oxygen is typically not available. Facultative and strict anaerobic bacteria have the ability to use other oxidizing agents/electron acceptors to carry out respiration. Anaerobic and facultative bacteria will use the electron acceptor which yields the highest energy, or the acceptor which is most readily available. The availability and concentration of electron acceptors changes as the soil profile increases in depth.

**Electron Tower**

[](http://microbewiki.kenyon.edu/index.php/File:Environmental1.gif)

[http://microbewiki.kenyon.edu/skins/common/images/magnify-clip.png](http://microbewiki.kenyon.edu/index.php/File:Environmental1.gif)

Electron tower

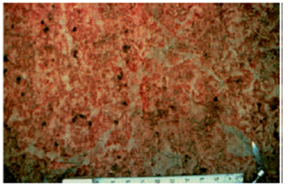
Electron tower theory explains the utilization order of electron acceptor for respiration. Depending on the type of electron acceptors used by microorganisms, microbes can be classified as strict aerobes, obligate anaerobes, and facultative anaerobes. Strict aerobes can not live under anoxic condition; on the contrary, obligate anaerobes can never use oxygen as electron acceptor. However, facultative anaerobes can live in both aerobic and anaerobic condition. If oxygen is plentiful, they tend to use oxygen because microorganisms gain much energy from reducing oxygen rather than other electron acceptors. When there is no more available oxygen in solution, microbes will choose to use nitrate as an electron acceptor (if available). Thus, obligate anaerobes and facultative anaerobes use alternative electron acceptors in the order of electron acceptor having the most reducing energy. Oxygen is the most efficient electron acceptor, while carbon dioxide has the least amount of reduction potential.

**Gleyed Soils and Recovery to Aerobic Conditions**

[](http://microbewiki.kenyon.edu/index.php/File:Gleyed_soil.png)

[http://microbewiki.kenyon.edu/skins/common/images/magnify-clip.png](http://microbewiki.kenyon.edu/index.php/File:Gleyed_soil.png)

Gleyed soil from Prof. Scow's lecture note 2008

[](http://microbewiki.kenyon.edu/index.php/File:Oxidized_soil.png)

[http://microbewiki.kenyon.edu/skins/common/images/magnify-clip.png](http://microbewiki.kenyon.edu/index.php/File:Oxidized_soil.png)

Oxidized soil from Prof. Scow's lecture note 2008

[](http://microbewiki.kenyon.edu/index.php/File:Winogradsky_column.jpeg)

[http://microbewiki.kenyon.edu/skins/common/images/magnify-clip.png](http://microbewiki.kenyon.edu/index.php/File:Winogradsky_column.jpeg)

[Winogradsky column](http://dwb.unl.edu/Teacher/NSF/C11/C11Links/helios.bto.ed.ac.uk/bto/microbes/winograd.htm)

**Soil Gleying**: Gleying is a phenomenon in which waterlogged soils are discolored by accumulation of Fe(II) due to reduction of ferric iron into ferrous iron (Lovely 1991). Although ferric iron exists as an insoluble form in flooded soils, more ferrous iron can accumulate by the reduction of ferric iron over time. This results in a greenish, blue, grey soil color. In general Fe(III)-reducing fermentative bacteria can be readily isolated from gleyed soils. The black color of soils/solution is frequently observed in flooded soil. This may result from the formation of iron sulfides (FeS) and pyrite (FeS2) (Wenk and Bulakh 2004).

**Recovery to Aerobic Conditions** When waterlogged soils drain, the Eh starts to increase as oxygen diffuses into soil pores. Plentiful oxygen represses the activity of anaerobes, which results in an increase of aerobic microbes. If oxygen diffuses deep into the soil profile, the production of H2S ceases. Under aerobic conditions, ferrous iron is oxidized by iron-oxidizing bacteria, resulting in the formation of ferric oxides or ferric hydroxide minerals. The gray color in soil changes to a red, yellow, or brown color as these minerals are oxidized. At higher Eh zones ( > 500 mV), undecomposed soil organic matter is used as an electron donor by aerobes and converted to water and CO2 (Richardson and Vepraskas 2000). In aerobic condition, manganese can be readily oxidized to MnO2. Black soil is often shown in aerated soil because manganese oxide is a mineral with a black color.

**Variation of pH and Eh**

**pH**

**Neutral pH soil**

When soil is saturated with water, pH drops at first due to organic acid produced from fermentation. Then, pH gradually starts to rise as a result of the buffering capacity of the soil. The half reactions of hydrogen consumption are as follow;

Aerobic respiration: ½ O2 + 2e- + 2H+ -> H2O (by facultative anaerobes and aerobes)

Denitrification: 2NO3- + 12 H+ +10e- -> N2+6H2O (by denitrifiers)

Manganese reduction: MnO2 + 4H+ + 2e- ->Mn2+ + 2H2O (by manganese reducing bacteria)

Iron reduction: Fe(OH)3 + 3 H+ + 2e- -> Fe2+ + 2H2O (by iron reducing bacteria)

Sulfate reduction: SO42- + 10H+ +8e- -> H2S + 4H2O (by sulfate reducing bacteria)

Methane production: CO2 + 8 H+ + 8e- -> CH4 +2 H2O (by methanogens)

**Eh**

During the succession of anaerobic oxidation processes, the redox potential (Eh) of flooded soils will decrease as a result of the reduced products formed. Approximate values for redox potentials associated with specific oxidation-reduction process are as follows:

|  |  |
| --- | --- |
| Observation | Eh (mV) |
| Disappearance of oxygen | +330 |
| Disappearance of nitrate | +220 |
| Appearance of manganese ions | +200 |
| Appearance of ferrous iron ions | +120 |
| Disappearance of sulfate | -150 |
| Appearance of methane | -250 |

**Solubility/Mobility of Minerals**

Since the toxicity, solubility, mobility, and bioavailability for a given element or compound is mainly influenced by soil solution reduction potential and pH, flooded soil conditions play an important role in the mobility of trace metal, nutrients, and minerals.

**Plant Nutrient Availability**

[](http://microbewiki.kenyon.edu/index.php/File:Overwater.jpg)

What over-watering looks like in a common house plant?

Flooded soils can prevent efficient gas exchange between the plant root and the soil. pH plays a major role in healthy plant growth. In flooded soils, under anaerobic conditions, the pH will tend to rise initially. Denitrification of soil nitrate to nitrogen gas plays a major role in the rise of pH levels. Flooding results in poor soil aeration because the supply of oxygen to flooded soil is severely limited. Oxygen deficiency is likely the most important environmental factor that triggers growth inhibition and injury in flooded plants. Microorganisms will begin to use available plants nutrients as alternative electron acceptors, such as sulfate, nitrate and iron(III).

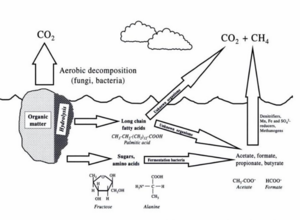
Experiments have been done on soybean plants to show the effects of flooded soils. Flood duration effects on soybean plants resulted in yellowing and abscission of leaves at the lower nodes, stunting, and reduced dry weight and seed yield. Canopy height and dry weight decreased linearly with duration of the flood at both growth stages. Growth rates were 25 to 35% less when soybeans were flooded (3).

**Microbial processes:**

**Microbial Activity:**

In anaerobic respiration oxygen is replaced by other compounds as [TEA (terminal electron acceptors)](http://en.wikipedia.org/wiki/Electron_acceptor). Some important terminal electron acceptors include iron, nitrate, sulfate, and manganese. These processes are primarily driven by microbial activity. Energy yields of alternative electron acceptors are lower than that of aerobic respiration, in which oxygen is utilized as a TEA (see [#Electron Tower](http://microbewiki.kenyon.edu/index.php/Flooded_soils#Electron_Tower) theory. As available oxygen declines, organisms that thrive under anoxic conditions proliferate using alternative electron acceptors. The order in which available electron acceptors are consumed can generally be predicted by the electron tower and associated energy yields of electron pairs. Changes in redox conditions of flooded soils over time reflects the successive availability of TEA's from the electron tower, and will govern which microbes will thrive, as those able to use these available alternative electron acceptors. Flooding also alters microbial flora in soil by decreasing the O2 concentration. Fermentation is a major biochemical processes responsible for organic matter decomposition in flooded soils. Eh levels can affect which compounds are fermented. These levels will tend to gradually drop in flooded soils.

**Fermentation under Anoxic Conditions:**

[](http://microbewiki.kenyon.edu/index.php/File:Anaerobic_decomposition.png)

[http://microbewiki.kenyon.edu/skins/common/images/magnify-clip.png](http://microbewiki.kenyon.edu/index.php/File:Anaerobic_decomposition.png)

Organic matter decomposition pathways . [Richardson and Vepraskas](http://microbewiki.kenyon.edu/index.php?title=Richardson_and_Vepraskas&action=edit&redlink=1)

There are many types of fermentative bacteria in soils, such as the genus [*Bacillus*](http://microbewiki.kenyon.edu/index.php/Bacillus), [*Clostridium*](http://microbewiki.kenyon.edu/index.php/Clostridium), and [*Lactobacillus*](http://microbewiki.kenyon.edu/index.php/Lactobacillus). 4 ATP molecules per molecule of glucose are produced by fermentation, while 38 ATP molecules are produced by aerobic respiration. Although the energy yield via fermentation is less than respiration, fermentation plays an important role in anaerobic respiration for obligate and facultative anaerobic bacteria, including denitrifier, Fe3+, Mn4+, SO42-, reducers, and methanogens. Sugar (glucose or fructose) is broken down into simple compounds (e.g. formate, acetate, and ethanol) during fermentation. Also, numerous fermentation products, such as carbon dioxide, fatty acid, lactic, alcohols, are released into soils. These compounds serve as substrates for other anaerobic bacteria. Thus, low molecular weight organic compounds produced from fermentation influence the reduction of Fe(III), Mn(IV), SO42-, and CO2(Richardson And Vepraskas 2000).

**Organisms involved in Flooded Soils**

**Nitrate Reducing Bacteria**

When available oxygen is depleted and nitrate is available, denitrification, the reduction of NO3- to NO,N2O,or N2, primarily occurs. Denitrification is carried out by obligate respiratory bacteria belonging to the genera [*Agrobacterium*](http://microbewiki.kenyon.edu/index.php/Agrobacterium), [*Alcaligenes*](http://microbewiki.kenyon.edu/index.php/Alcaligenes), [*Bacillus*](http://microbewiki.kenyon.edu/index.php/Bacillus), [*Paracoccus denitrificans*](http://microbewiki.kenyon.edu/index.php/Paracoccus_denitrificans), [*Pseudomonas*](http://microbewiki.kenyon.edu/index.php/Pseudomonas) and [*Thiobacillus*](http://microbewiki.kenyon.edu/index.php/Thiobacillus) (Knowles, 1982). Nitrate ammonification found in facultative anaerobic bacteria belonging to the genera [*Bacillus*](http://microbewiki.kenyon.edu/index.php/Bacillus), *Citrobacter* and [*Aeromonas*](http://microbewiki.kenyon.edu/index.php/Aeromonas), or members of the *Enterobacteriaceae* (Cole and Brown, 1980; Smith and Zimmerman, 1981; MacFarlane and Herbert, 1982). Strictly anaerobic bacteria belonging to the genus [*Clostridium*](http://microbewiki.kenyon.edu/index.php/Clostridium) are also able to reduce nitrate to ammonia (Hasan and Hall, 1975). Pure culture studies show evidence that nitrate reduction may also occur in the presence of oxygen (Kuenen and Robertson, 1987).

**Iron/Manganese Reducing Bacteria**

Most microorganisms can reduce Mn4+ and Fe 3+. Ferrous iron is used as electron acceptor by iron-reducing bacteria such as [*Geobacter*](http://microbewiki.kenyon.edu/index.php/Geobacter)*([Geobacter metallireducens](http://microbewiki.kenyon.edu/index.php/Geobacter_metallireducens" \o "Geobacter metallireducens) and* [*Geobacter sulfurreducens*](http://microbewiki.kenyon.edu/index.php/Geobacter_sulfurreducens)*),Shewanella putrefaciens,*[*Desulfovibrio*](http://microbewiki.kenyon.edu/index.php/Desulfovibrio)*,* [*Pseudomonas*](http://microbewiki.kenyon.edu/index.php/Pseudomonas)*,* and [*Thiobacillus*](http://microbewiki.kenyon.edu/index.php/Thiobacillus)(Lovley 1993). [*Bacillus*](http://microbewiki.kenyon.edu/index.php/Bacillus)*,* [*Geobacter*](http://microbewiki.kenyon.edu/index.php/Geobacter)*,* and [*Pseudomonas*](http://microbewiki.kenyon.edu/index.php/Pseudomonas) are representative manganese-reducing bacteria. Different forms of ferric iron oxides exist in drained aerobic soils as well as in waterlogged soils. Not all forms of ferric oxides are equally suitable for reduction by ferric oxide reducer bacteria (Gotoh and Patrick, 1974; Schwertmann and Taylor, 1977). In general, amorphous forms are more efficient for ferric reducer bacteria than crystalline forms (Lovely and Phillips, 1986). The reduction of ferric oxide may release phosphate and trace elements that are adsorbed to amorphous ferric oxide and thus enhance availability of these compounds in the soil (Lovely and Phillips, 1986).

**Sulfate Reducing Bacteria**

Bacteria can use organic compounds as an electron donor and sulfate as an electron acceptor. This reaction for acetate as electron donor is as follows:

CH3COO- + SO42- + 3 H+ ---> 2CO2 + H2S + 2 H2O

This reaction is carried out by sulfate-reducing bacteria such as [*Desulfobacter*](http://microbewiki.kenyon.edu/index.php/Desulfobacter), *Desulfobulbus*, [*Desulfococcus*](http://microbewiki.kenyon.edu/index.php/Desulfococcus), [*Desulfovibrio*](http://microbewiki.kenyon.edu/index.php/Desulfovibrio), [*Desulfosarcina*](http://microbewiki.kenyon.edu/index.php/Desulfosarcina),*Desulfotomaculum*,and *Desulfonema*(Langston and Bebiano 1998, Sylvia 2004). Some of the sulfate reducing bacteria oxidizes the organic compounds completely to CO2 and some other stop after producing acetate as an intermediate of oxidation. Hydrogen sulfide gas produced via anaerobic respiration causes the rotten egg odor. Recently, Boetius et al and Orphan et al revealed that a consortium of [*Desulfosarcina*](http://microbewiki.kenyon.edu/index.php/Desulfosarcina) and methanotrophic archaea in the sediments contribute to control methane gas.

CH4 +SO4 2------->HCO3+HS -+H2O

[**Methanogens**](http://microbewiki.kenyon.edu/index.php/Methanogens)

Methanogen products less energy than other reducing reaction because the reduction of carbon dioxide occur under the most anaerobic and reduced conditions(see [#Electron tower](http://microbewiki.kenyon.edu/index.php/Flooded_soils#Electron_tower) section). Thus, the activity of methanogen is repressed until other alternative terminal electron acceptor such as Fe(III), NO3-,and SO42-, have been depleted.

Methanogen (e.g *Methanobacterium formicum*, *Methanobacterium bryantii*, *Methanobacterium thermo-autrotrophicum*, and etc ) can use CO2 and produce methane (Langston and Bebiano 1998)

Greenhouse Gas Emissions from Flooded Soils

Flooded soils are dynamic ecosystems that play an important role in biogeochemical cycling and in the production of greenhouse gases. Methane (CH4+) and nitrous oxide (N2O) are produced as byproducts of anaerobic metabolism in the low-redox zones characteristic of flooded soils, where oxygen is lacking. Carbon dioxide (CO2), which receives widespread attention as a greenhouse gas and potential source of global warming, may also be produced at the interface of anaerobic-aerobic zones through the consumption of methane gas. However, it should be noted that from a global standpoint methane and nitrous oxide on a per molecule basis have the potential to contribute 25x and 300x more to global warming over the next century than carbon dioxide, respectively (Schlesinger, 1997). Thus the conversion of methane gas to carbon dioxide essentially reduces the greenhouse gas effect by 25x per molecule per 100 years. According to Matthews and Fung (1987), an estimated 3.6% of terrestrial land is classified as wetlands, and although this number continues to decline (Schlesinger, 1997) the effect of flooded soils to the global climate is clear.

**Methane Production; Methanogenesis**

[](http://microbewiki.kenyon.edu/index.php/File:Methane.jpg)

[http://microbewiki.kenyon.edu/skins/common/images/magnify-clip.png](http://microbewiki.kenyon.edu/index.php/File:Methane.jpg)

A natural source of methane gas

Methane production occurs exclusively in anaerobic conditions by a group of Archaea known as methanogens. These microbes are obligatory, and require extremely low redox conditions in the range of -100mV (see [#electron tower](http://microbewiki.kenyon.edu/index.php/Flooded_soils#electron_tower) theory, section 2.1.1) (Sylvia, 2005). If oxygen is introduced into the system, methanogenesis ceases; thus, the process of methanogenesis depends on saturated soil conditions.

Methanogenesis can occur via one of two pathways: either by 1) CO2 reduction or by 2) acetate fermentation.

1) CO2 + H2 --> CH4+ (CO2 reduction)

and

2) CH3COOH --> CH4+ + CO2 (acetate fermentation)

Both acetate and hydrogen are byproducts of anaerobic fermentation.

Because the process of methanogenesis is “fed” byproducts produced from a complex series of degradation processes which are themselves “fed” complex organic matter, rates of methane production are highly sensitive to changes in temperature. Methanogenesis has a Q10 value in the range of 30-40, which is substantially higher than most biochemical process (Sylvia, 2005).

Despite the clear effect of increasing temperatures on the rate of methanogenesis, the actual impact of global warming on methane production rates in wetlands and permafrost regions is highly unpredictable. Because methanogenesis requires anoxic conditions, any drying of flooded soil environments would both decrease methane production and increase methane oxidation, reducing overall methane emissions. Alternatively, warmer climates could increase growing seasons, which would increase methane emissions (Sylvia, 2005).

**CO2 Production via Methane Consumption: Methanotrophy**

Some of the methane produced via methanogenesis in flooded soils may be consumed and oxidized to CO2 at the interface of the anaerobic-aerobic zones. This process occurs primarily by a group of bacteria known as methanotrophs. These microbes can be found in surface layers of wetland soils and unsaturated upland soils, and may be exposed to very high concentrations of methane gas, sometimes amounting to 10% or more of the dissolved gases. Methane is thought to be the only source of C and energy for these bacteria.

Methanotrophy occurs in the following reaction:

CH4+ + 2O2 --> CO2 + 2H2O

Methane is similar in size and shape to ammonium; and there is some evidence that nitrifiers (ammonium oxidizers) can also oxidize methane (Sylvia, 1998). Because they are molecularly similar, NH4+ competes at the enzyme’s active site, inhibiting methane oxidation. As a result, methanotrophy is generally inhibited by the addition of fertilizer or excess nitrogen in the system, when ammonium levels are high.

Alternatively, if nitrogen is extremely limiting the addition of nitrogen will stimulate methanotrophy and actually increase methane consumption. So although it is generally expected that adding N-fertilizer will decrease CH4+ consumption and lead to increased global warming potential, sometime the opposite effect may occur. (Sylvia, 2005).

**Nitrous Oxide; Denitrification**

Denitrification is an anaerobic process in which nitrate serves as the terminal electron acceptor, and generally some source of organic carbon is the electron donor (also H2 may serve as a donor).

In this process, nitrate is oxidized to nitric oxide, then nitrous oxide, and then fully oxidized to dinitrogen:

NO2- --> NO --> N2O --> N2

However, under certain conditions the full oxidation of NO3- to N2 does not occur and nitrous oxide (N2O) is produced.

Microbes responsible include both organotrophs and lithotrophs, and this process occurs primarily by facultative anaerobes.

Although a low redox potential is important for denitrification to occur (oxygen must not be present or it will “out-compete” nitrate as a terminal electron acceptor), redox requirements are not so low that this process cannot occur within anaerobic microsites of soil aggregates.

Factors affecting nitrous oxide production include oxygen, pH, and the ratio of nitrate to available C. Although denitrification rates decrease with increasing oxygen, the proportion of N evolved as nitrous oxide actually increases with increasing oxygen. Low pH generally inhibits the reduction of N2O to N2; thus at low pH, N2O will likely dominate. However, highly acidic soils have low N availability and low nitrification and denitrification rates. Thus, the highest rate of nitrous oxide production from denitrification occurs in moist soils that cycle N rapidly (Sylvia, 2005).

**Accumulation of photo toxic substances**

Under an aerobic conditions, many phto toxic substances are produced and released in the soil by stressed plants .These ion clued,

1. organic aids such as acetin acid, formic acid, propionic acid, butyric acid and valeric acid .

2. aromatic acids such as ethylene, hydrogen,C02, nitric oxidesw.

3. hydrogen sulphide is formed in mud of waterlogged soils by the reduction of sulphates . H2S can reduce H2SO4 and SO2 that is nearly 50 times more toxic than H2S.

**Enzymatic activity in waterlogged soils**

Recent enviromental findings BY “Chandra” demonstrated that an increase in the dehydrogenase activity and marked decrease in invertase activity in the flooded soils.

**Crop response to water logging or effects of water logging on crop growth**

**Morphological and anatomical effects**

Typical effects of water logging on the growth of shoot include,

Reduced elongation

Chlorosis

Senescence

Abscission of lower leaves

Wilting

Hyper trophy(abnormal size than normal)

Epinosity(drooping of leaves)

Adventitious roots formation lower parts of the stem.

Lnticells formation(small pores at the base of the stem)

Aerenchyma formation

Leaf curling

Decline in relative growth rate

Root growth is also affected by water logging

Root elongation is sloed down

Root hair formation is inhibited. Under prolonged flooded conditions, roots may bracken and eventually rot. Under water logging many plants form air spaces in cortex of their roots.

In cultural solutions, Aerenchyma tissue were formed in the roots of maize and wheat , whereas in aerated soils no aerenchyma wre formed in these plants. Similarley, the roots of barley plant were grown for two months in non aerated culture solution, formed aerenchyma n the root cortex and these roots were straighter shorter and thicker. It is also said that IAA, Ca and Ethylene accumulation is responsible for the aerenchyma formation. It is also said that lack of O2 sets off a series of biochemical reactions that lead to the ultimate destruction and death of clusters of cells in the cortex and subsequent formation of inter cellular air spaces.

**Physical and biochemical affects**

1. **Hormonal metabolism in water logged soils**

In normal soils ,IAA, Gibberellin , Cytokines, Ethylene and ABA are formed in the plant body. Hormonal metabolism is altered greatly by water logging. All major groups of plant hormones have been investigated. One of the chief effect of water logging I sto upset the hormonal metabolism and their transport between their roots and shoots this may result in

a) Decreased supply of hormones from the root to the shoot required for the normal shoot growth (Gibberellin).

b) Increased supply of substances from the root to the shoot.

c) Accumulation of substances in the shoot, normally exported to the roots (Auxin).

A number of workers have stated that cytokinines and gibberlines are produced in roots and transported via the transpiration stream to the shoot conversely, auxin are produced in the shoot and it is thought that they move downward from the shoot to regulate the root growth . Kramer and Phillips proposed that lack of O2 in the lower portion of the shoot might cause the disease in the auxin transport to the root. This result in

Poor rooting

Adventitious rooting

Stem swelling

As was observed in the sunflower, during flooding, auxin accumulation in the shoot resulted in more ethylene production that caused Epinasty.

Several workers have suggested that reduced stem elongation of flooded plants due to inhibition of Gibberellic acid synthesis or cytokinin production in the roots or their transport. ABA level was high in the plants growing on water logged soils copared to those growing in normal soils which causes wilting of leaves.

Recent studies have shown hat under anaerobic conditions a single hormone is produced in the roots and transported to the shoots where it stimulates to the Ethylene production. This single hormone is identified as 1-aminocyclo-propane-1 carboxylic acid (A.C.C) which is an intermediary in the conversion of methionine to ethylene. An increase in A.C.C contents occurred in the plants growing under water logging conditions resulting in increased ethylene production that caused epinostic curvature.

**2)** **Respiratory metabolism**

A shift from aerobic to anaerobic conditions inhibits electron transport and decreased ATP production. It is followed by accumulation of various end products of aerobic respiration and rapid depletion of organic compounds. It was found that under an aerobic conditions, there was an increased ethanol and alcohol dehydrogenase activity. The lipid metabolism was increased. The rice seedling growing in an aerobic condition s was found to have double amount of lipids.

**3)** **Water and mineral uptake**

Low oxygen affects the water and mineral uptake by

1. Changing the nutrients uptake
2. Low metabolic status of the plants.

Karamer reported hat due to low transpiration pull and increased osmotic pressure, the water uptake was adversely affected under water logged conditions.

Drew and sissore reported that when oxygen concentration dropped below 2% in the soil it results in dereased nitrogen uptake in Barley seedlings and the plant showed chlorosis. Similarly in peas nitrogen uptake inhibited severely by low oxygen concentration. However phosphorus and potassium were less affected. Ca and Mn uptake was not altered.

Layshon Sheared reported tat the Barley plants when exposed to short period of flooding, resulted in reduction of of nitrogen uptake by 51% phosphorus uptake by 61% and potassium by 58%.

1. **Photosynthesis**

The effect of water logging on photosynthesis is not well documented.

1. **Nitrogen fixation**

Excess of soil moisture is determined to the development and function of nodules in the legumes. Due to reduced availability of oxygen there was a reduction in nodules mass or weight of cowpeas, beans and peas.

**Fertilization in water logged soils**

NH4NO3 should not be use early in the season. Urea is the probably the best fertilizer. SSP is also toxic. Rock phosphate is the best form for sodic rice fields. Urea gives NH4, which can be taken up by the plants .Nitrogen in the ammonium nitrate is not advised because reduction of nitrate takes place under anaerobic conditions.

**Crop management factors on water logged soils**

Selection of suitable crop variety

Improve drainage

Seepage should be checked

Pumping of water

Hardpan

Land leveling

Green manuring

Sowing on ridges

Restricted irrigation