LECTURE NOTE

SOS 312

SOIL CHEMISTRY AND MICRO-BIOLOGY

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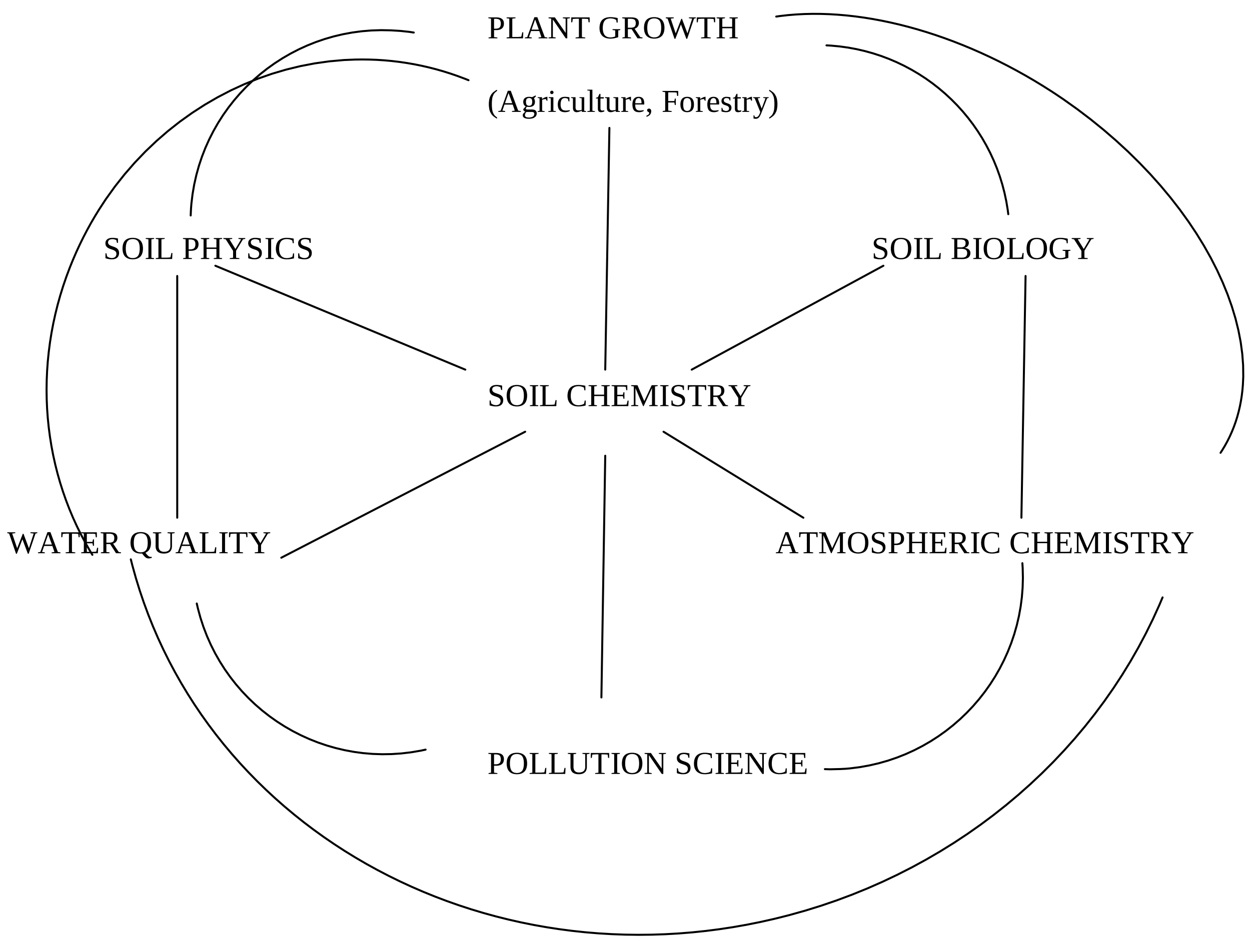
INTRODUCTION TO SOIL CHEMISTRY

Soil Chemistry is an important branch of soil science. It is fundamental to all soil processes that affect the use of soil. Soil chemistry studies the nature of chemical elements in the soil system in organic and inorganic combinations. It also studies the inter-relationship between these chemical elements and how they relate with three states of matter.

Soil chemistry is regarded as the most central of all the scientific disciplines that interact to make up of the complex web of environmental science. This is illustrated in the figure in the figure below:



Schematic representation of the interaction between soil chemistry and other branches of soil science and environmental science

- **Soil chemistry and plants**
- **Soil chemistry, soil biology and biochemistry**
- **Soil chemistry and soil physics**
- **Soil chemistry, geochemistry and soil formation**
- **Soil chemistry and water chemistry**
- **Soil chemistry and pollution science**

Significance of soil chemistry

Understanding soil chemistry is very important to crop production in terms of

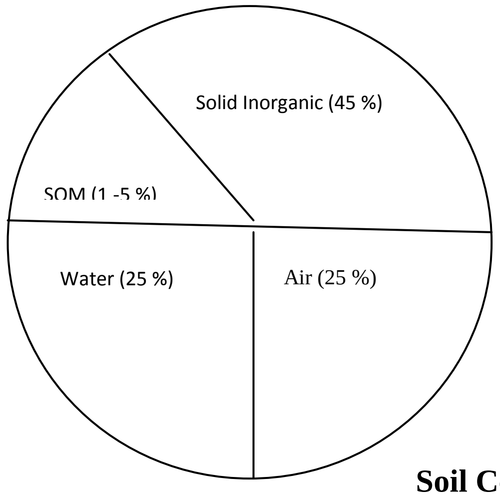
1) Improving the availability of nutrients to plants
2) To utilize soil microbial organisms to the best advantage
3) To improve the physical conditions of the soil
4) Helps to explain the basic properties of soils as they occur in nature
5) Helps to monitor and follow rapid changes that occur in the soil as a result of the introduction of intensified modern techniques in crop production

SOIL COMPOSITION

Soil may be defined as material of variable depth with a substantial solid content at the Earth's surface which is undergoing change as a consequence of chemistry, physics and biology processes.

Soil essentially consists of three phases; a solid phase, a solution phase and a gas phase.

- The solid phase usually includes an intimate mixture of mineral material, originating from rock, sediment or till, and organic material arising as a consequence of biological activity
- 2. The solution phase, this interact continuously with the solid phase. It originates infiltrating the soil or from rising water or water moving laterally.
- 3. The gas phase, or soil atmosphere composition depends upon biological activity.



Soil Composition (Hypothetical)

SOIL COLLOIDS

- Next to photosynthesis and respiration, no process in nature is more vital to plant and animal life than the exchange of ions between soil particles and plant roots.
- These cation and anion exchanges occur mostly on the surfaces of the finer or colloidal fractions of both the inorganic and organic matter (clay and humans).
- Colloids are substances whose particle size is about 1 to 1000nm when they are mixed with another substance, usually air or water.
- Colloids are action sites for chemical reaction, microscopic, large surface area. The larger the surface area, the better they are for chemical reaction.
- Molecules of some compounds can come within the colloidal range but most colloids consist of aggregate of molecules. Colloids are so ubiquitous in nature and so distinctive that they have common names as fog, smoke, aerosol, foam, emulsion, soil and clay. All are small particles suspended in a fluid. as

General properties of soil colloids

- **Size**
- **Surface area**

- **Surface charges**
- **Adsorption of cations and water**

Types of soil colloids

There are four major types of colloids present in soil

1. Layer silicate clays
2. Iron and Aluminum oxide clays
3. Allophane and associated clays
4. Humus

(Generally 1, 2, 3 are inorganic while 4 is organic colloids)

Sources of charges on soil colloids

There are two major sources of charges on soil colloids:

1) Hydroxyls and other such functional groups on the surfaces of the colloidal particles that by releasing or accepting H^+ ions can provide either negative or positive charges.
2) The charge imbalance brought about by the isomorphous substitution in some clay structures of one cation by another of similar size but differing in charge.

Permanent charges

- **Negative charges**

A net negative charge is found in minerals where there has been an isomorphous substitution of a lower charged ion (e.g. Mg^{2+} for a higher-charged ion (e.g. Al^{3+}).

- **Positive charges**

Isomorphous substitution can also be a source of positive charges if the substituting cation has a higher charge than the ion for which it substitutes.

pH- dependent charges

- **Negative charges**

The pH-dependent charges are associated primarily with hydroxyl (OH) groups on the edges and surfaces of the inorganic and organic colloids. The OH groups are attached to iron and/or Al in the inorganic colloids (e.g. Al-OH) and to the carbon in CO groups in humus (e.g. –CO-OH). Under moderately acid conditions, there is little or no charge on these particles, but as the pH increases, the hydrogen dissociates from the colloid OH group, and negative charge result.

Positive charges

Under moderate to extreme acid soil conditions, some silicate clays and Fe, Al oxides may exhibit net positive charges. The exposed OH groups are involved. In this case, however, as the soils becomes more acid, (protonation), the attachment of H^+ ion to the surface OH groups takes place.

SILICATE MINERAL CHEMISTRY

The silicate minerals are responsible for the important, physical and chemical properties of most soils. Silicate minerals characteristically contain Si, O_2 and Al.

Silicon

It makes up of 27.6% of the Earth crust, second to O_2. Si compound make up of the framework for most soils except tropical soils. It is amphoteric and usually slightly acidic, forming weak acid.

Definition of clays

Clays are the active mineral portion of soils dominantly colloidal and crystalline. The crystalline nature of clays is such that they have definite repeating arrangement of atoms which they are composed of. Majority are made of planes of O_2 atoms with Si and Al atoms holding the O_2 together by ionic bonding.

Classification of clays

Clays are usually given group names based on their structure or on purely chemical composition. There are 3 groups.

1) **Silicate clays: -** These are crystalline clays e.g. Montmorillonite, illite, vermiculite, kaolinite, chlorite. Each crystalline clay is like a particular deck of cards. Each card represent a layer each of which is an exact replication of each other layer.

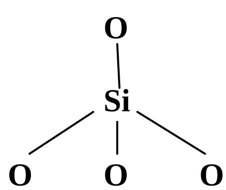
2) **Amorphous clays:-** These are non-crystalline, which have silica, they are mixtures of Si and Al that have not formed well oriented crystals but sometimes have high cation or anion exchangeable capacity.

3) **Sesquioxides:-** These consists of groups of Fe, Al and Ti oxides clays. They are present in condition where there is excessive leaching caused by rainfall and sometimes intensive weathering of minerals in humid warm climate. They can be crystalline or armorphous.

Structures of layer silicate clay

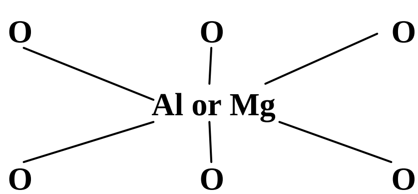
This implies the basic building blocks of clays. All soil clays are formed from the same 2 basic structural units. It is the way these 2 basic building units are put together that gives the soil clay distinctly different properties. They are:

1) **Silica tetrahedron:-** This is a silica dominated sheet is a unit composed of one silicon atom surrounded by four oxygen atoms.



SiO_4

2) **Aluminum and/or Mg octahedron:-** In this unit, an Al or Mg is surrounded by 6 oxygen atoms or hydroxyl groups, the center of which define the apices of an 8-sided solid. .



Al_2O_6 or Mg_3O_6

MINERALOGICAL ORGANIZATION OF SILICATE CLAYS

On the basis of the number and arrangement of tetrahedral (silica) and octahedral (Al-Mg) sheets contained in the crystal units or layers, silicate clays are classified into two different groups, 1:1 – type minerals and 2:1 – type minerals.

1:1 type minerals

The layer of the 1:1 type minerals are made up of one tetrahedral (silica) sheet and one octahedral (alumina) sheet hence the terminology 1:1 type crystal. Kaolinite is the most prominent member of this group, others are halloysite, nacrite and dickite.

Characteristics of kaolinite

1) It has strong H-bonding
2) It does not allow water to penetrate between the layers and have almost no swelling
3) It has low cation exchangeable capacity.
4) Kaolinite exhibits less plasticity (capacity to be molded), stickiness, cohesion, shrinkage or swelling.
5) Kaolinite containing soils make good bases for road beds and building foundations.

2:1 type minerals

The crystal unit (layers) of these minerals are characterised by an octahedral sheet sandwiched between two tetrahedral sheets. Four general groups have this basic crystal structure. Two of them, smectite and vermiculite (expanding – type) and the other two fine-grained (illite) and chlorite (non expending).

Expanding minerals

- **The smectite group**

Characteristics of smectites

1) High plasticity and cohesion
2) Their marked swelling when wet and shrinkage on drying
3) Has high CEC
4) Permeability to water is low.

- **Vermiculites**, these are also 2:1 type minerals, an octahedral sheet being found between two tetrahedral sheets. In most soil verticulites, the octahedral sheet is aluminum dominated (dioctahedral), although Mg-dominated (trioctahedral) vermiculites are also found.
- **Non-expanding minerals**

  Micas and chlorites are the types of minerals in this group.
- **Muscorite and biotite** are examples of unweathered micas often found in sand and silt separates.
- **Soil chlorites** are basically Fe-Mg silicates with some Al present.

The ion exchange phenomenon

The importance and ability of clay minerals and colloidal to hold cations cannot be over emphasized, these serves as the store house for many nutrients required for plant growth. The soil system provides a buffer system that tends to maintain the nutrients in correct proportions required by plants. Soil colloid have unneutralised negative charges, thus positively charged ions (cations) are adsorbed at these negatively charged sites by electrostatic attraction, these adsorbed cations resist removal by leaching water but can be replaced by other cation in solution by mass action. The exchange of one positive ion by another is called cation exchange. C.E. takes place on the surfaces of clays and humus colloids as well as on plant root surface. Cations on exchange sits are Ca^{2+}, Mg^{2+}, H^{+}, K^{+}, Al^{3+},NH_4^{+}, Na^{+}, etc.

- **Cation Exchange Capacity (CEC)**

This is the amount of exchangeable cations that soil can adsorb. By standard methods al the adsorbed cations in a soil are replaced by a common ion, such as Ba^{2+}, K^{+}, or NH_4^{+}; then the amount of adsorbed Ba^{2+}, K^{+} or NH_4^{+} is determined.

- **Anion Exchange Capacity (AEC)**

This is the amount of exchangeable anions that soil can adsorb.

THE SOIL AS A CHEMICAL SYSTEM

Introduction

Soil is a mixture of inorganic and organic solids, air, water, and microorganisms. These components of the soil interact together chemically on continuous basis such that the soil may be viewed as a chemical system.

Soil Chemistry studies the soil as a chemical system. It is a branch of soil science that focus mainly on the reactions involved in the soil solution and the solid-liquid interface. It also studies the interactions among ions in the soil. All the basic concepts in chemistry are important in Soil Chemisty as a course of study.

THE SOIL AS A CHEMICAL SYSTEM

Soil Colloids

Colloids are particles, which may be a molecular aggregate, with a diameter of 0.1 to 0.001 mm. Soil clays and soil organic matter are often called soil colloids because they have particle sizes that are within or approach colloidal dimensions. Colloids go into suspension in a solution — they float around without settling out for great lengths of time.

Colloids have properties that are important in soil chemistry, such as the ability to adsorb cations because most soil colloids carry negative charges on them. Because of this, they are also referred to as polyanions. Soil colloids are also called micelles. A knowledge of silicate clay chemistry will help us to understand the properties of soil colloids.

Soil Solution

The water in the soil is referred to as the soil solution because it contains dissolved materials (cations and ions) as well as suspended colloids of clay and organic matter.

Plants tend to get their nutrients from the soil solution. However, the solution does not contain sufficient nutrients at any one time to last the life of the plant. These nutrients are replenished from the pool of exchangeable nutrients (those that are adsorbed onto colloids). Still more nutrients are held in what is called the stable pool (bound up in solid form as minerals or organic matter).

ION EXCHANGE

Ion exchange refers to the process of exchange of ions between the solid and the liquid phase of the soil. When the process involves positively charged ions (cations), it is denoted as cation exchange. When the process is involves negatively charged ions (anions), it is denoted as anion exchange. Cation exchange is most common in soils particularly in soils where the soil colloids (exchange sites) are negatively charged. Anion exchange takes place mainly in acid soils, where the soil colloids are positively charged. Ion exchange also takes place between plant roots and ion in solution or between plant roots and soil colloids when in close contact. The process of ion exchange is vital to nutrient availability for plant uptake.

Cation Exchange Capacity (CEC)

It is primarily the ionic form of nutrients that plants are able to take up into their roots. Many of these nutrients are taken up in the cationic form, so it is important that the soil be able to supply these. Most soils have at least some ability to hold onto these ions at the negatively charged sites within the soil. The amount that they can hold is called the Cation Exchange Capacity. The cations are held to the edges of particles within the soil. This is referred to as adsorption. The cations in the soil are divided into acids and bases. The acids are predominantly hydrogen and aluminum. The bases are primarily calcium, magnesium, sodium, and potassium.

Technically, CEC can be defined as the sum of exchangeable bases plus total soil acidity at a specific pH value, usually 7.0 or 8.0. When acidity is expressed as salt-extractable acidity, the cation exchange capacity is called the effective cation exchange capacity (ECEC) because this is considered to be the CEC of the exchanger at the native pH value.

b) *Factors influencing CEC*

1. Amount of clay: Higher amounts of clay mean higher CEC.
2. Type of clay: Certain kinds of clay (smectites, montmorillonite) have higher CEC than others (such as kaolinite).
3. Amount of organic matter: Higher amounts of organic matter mean higher CEC
4. pH dependent CEC: Amorphous clay minerals and organic matter have a CEC that varies with pH. As pH increases, so does the CEC. Under acid conditions, these have an anion exchange capacity. For organic matter the rule of thumb is that for every pH unit above 4.5 there is a 1 meq/100g increase for each percent organic matter.

2. Base saturation

Base saturation refers to the percentage of exchange sites (negatively charged sites on clay and organic particles) that are occupied with bases (usually Ca^{2+}, Mg^{2+}, K^{+} and Na^{+}) as opposed to ions that make the soil acid (H+ or Al^{3+}). A more technical definition is the ratio of the quantity of exchangeable bases to the cation exchange capacity. The value of the base saturation varies according to whether the cation exchange capacity includes only the salt extractable acidity (see cation exchange capacity) or the total acidity determined at pH 7 or 8. Often expressed as a percent

$$\text{Percent Base saturation} = \frac{\sum (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+})}{CEC}$$

Exchangeable bases: These are basic cations (predominantly Ca^{2+}, Mg^{2+}, K^{+} and Na^{+}) adsorbed on the surface of soil colloids that can be readily replaced with a salt solution. Historically, these are called bases because they are cations of strong bases. Many soil chemists object to this term because these cations are not bases by any modern definition of the term.

Soils with high base saturations are considered more fertile because many of the "bases" that contribute to it are plant nutrients. Usually the base saturation is 100 percent when the pH is above about 6.5. Since rainfall tends to leach bases out of the soil, areas with higher rainfall tend to have lower base saturations than areas with lower rainfall, unless the parent material is high in bases (such as limestone).

Anion Exchange

Anions are not adsorbed onto soil particles to anywhere near the extent that cations are. This is due to the fact that clay minerals only have negative charges and that most of the exchange sites in organic matter also have negative charges. Many of the anionic nutrients are supplied through organic amendments from which they are released as the organic matter breaks down. Because there is little adsorption of the anions, many (particularly nitrates) are easily leached, which can lead to groundwater contamination. This can even happen in an organic farming situation if it is not well managed. Nutrients that are usually supplied by anions are nitrogen (NO_3^-), phosphorus ($H_2PO_4^-$, HPO_4^{2-}), sulfur (SO_4^-), chlorine (Cl^-), boron ($B_4O_7^{2-}$) and molybdenum (MoO_4^-).

Anion exchange capacity: The sum of exchangeable anions that a soil can adsorb. Usually expressed as centimoles, or millimoles, of charge per kilogram of soil (or of other adsorbing material such as clay).

Exchangeable anion: A negatively charged ion held on or near the surface of a solid particle by a positive surface charge and which may be easily replaced by other negatively charged ions (e.g. with a Cl^- salt).

Soil pH

Soil pH refers to the negative of the log of the concentration of hydrogen ions (moles per liter) in the soil. pH generally range in number between 0 and 14. Any pH below 7.0 denote acidic condition while any number above 7.0 denote alkaline condition. Water, H_20 or HOH, is usually in equilibrium with its constituent ions, H+ and OH- and has a pH of 7.) In acid soils (pH < 7), H+ ions predominate. In alkaline soils (pH > 7), OH- ions predominate. Soils with pH of 7 are neutral.

2. Effect of pH on nutrient availability and uptake

The pH of soil does not directly affect plants but it does affect the availability of different nutrients and toxic elements and their uptake by plant. This is mostly due to the fact that pH changes the form of many of the nutrients and many of the forms are relatively insoluble.

Acidity

Acidity refers to the condition of the soil when the exchange complex is dominated by hydrogen and aluminum ions. There are two forms of soil acidity; their technical definitions are: Acidity, salt-replaceable: The aluminum and hydrogen that can be replaced from an acid soil by an unbuffered salt solution such as KCl or NaCl. (Also known as exchangeable acidity.) Acidity, total: The total acidity including residual and exchangeable acidity. Often it is calculated by subtraction of exchangeable bases from the cation exchange capacity determined by ammonium exchange at pH 7.0. It can be determined directly using pH buffer-salt mixtures (e.g., BaCl2 plus triethanolamine, pH 8.0 or 8.2) and titrating the basicity neutralized after reaction with a soil.

2. Distribution of acid soils

Acid soils usually occur where there is sufficient rainfall or other sources of precipitation to leach the bases out of the soil. When this happens, the exchange complex becomes dominated by hydrogen (lowers pH) and aluminum (toxic). The higher the rainfall, the more the tendency of soil to become acidic

3. Problems associated with acidity

<u>Aluminum toxicity</u>: Aluminum is the third most common element in the earth's crust. It becomes more available at low pH's, and can be toxic to plants.

<u>Manganese toxicity:</u> This may occur in soil that are high in Mn and that have a pH less than 5

4. Acid soils and liming

Lime (calcium carbonate) is added to acid soils to raise the pH. Calcium replaces hydrogen and aluminum on exchange sites.

Alkalinity, salinity, and sodicity of soils

Soil alkalinity: The degree or intensity of alkalinity in a soil, expressed by a value >7.0 for the soil pH.

A soil is described as alkali if

(i) It has a a pH of 8.5 or higher or with an exchangeable sodium percentage greater than 0.15 (ESP>15).

(ii) It contains contains sufficient sodium to interfere with the growth of most crop plants.

Exchangeable Sodium percentage = [illegible] / CEC

Saline sc … wth of most crop plants. Salinity … er limit of saturation extract electrical conductivity of such soils is conventionally set at 4 dS m^{-1}(at 25°C).

Sodic soil: A non-saline soil that contains so high a level of exchangeable sodium as to adversely affect crop production and soil structure under most conditions of soil and plant type. The exchangeable sodium percentage (ESP) of at least 15

Saline-sodic soil: A soil containing sufficient exchangeable sodium to interfere with the growth of most crop plants and containing appreciable quantities of soluble salts. The exchangeable sodium ratio is greater than 0.15, conductivity of the soil solution, at saturated water content, of >4dS m-1(at 25°C), and the pH is usually 8.5 or less in the saturated soil.

OXIDATION –REDUCTION REACTIONS IN SOIL

Oxidation and reduction reactions are two reactions occurring simultaneously. These reactions are common in the soil. Oxidation is a reaction which involves gain of oxygen, or loss of hydrogen or electron. Reduction on the other side is the reaction which involves loss of oxygen, or gain hydrogen or electron. Oxidation – reduction reactions generally involve transfer of electrons from one substance to another (no bonding formed or broken).

Oxidizing agents (oxidizers) accept electrons from other substances.

Reducing agents (reducers) donate electrons to other substances.

Example: $Fe^{3+} + e^- \longleftrightarrow Fe^{2+}$

$$H_2O_2 + 2e^- + 2H^+ \longleftrightarrow 2H_2O$$

Source of electrons in soils.

Carbon atoms of organic matter are the main source of electrons in soils

Carbon has a wide range of oxidation states.

For example in the reaction,

$$CH_4 + 2O_2 \longleftrightarrow 2H_2O + CO_2$$

The oxidation state of carbon in CH4 is +4 while in CO_2 the oxidation number is -4. Thus in the reaction, 8e- are released

Other sources of electron in soil include nitrogen and sulfur atoms which can also exhibit several oxidation states. The availability of electrons usually controls the oxidation/reduction reactions and is expressed as redox potentials.

Soil microbes often serve as catalysis for the release of electrons from a substance.

Source of H+ (water).

Water is the main source of proton in the soil.

$$H_2O \longleftrightarrow H^+ + OH$$

Electron acceptors (oxidizers) in soils.

Electron acceptors in soil include oxygen, Fe, Mn, sulphate and nitrate ions. Oxygen is the most common electron acceptor under aerobic condition.

$$O_2 + 4e- + 4H+ = 2H_2O$$

Fe and Mn accept electrons under anaerobic conditions (in the absence of oxygen). Their reactions include the following

$$FeOOH + e- + 3H^+ \longleftrightarrow Fe^{2+} + 2H_2O$$

$$Fe_2O_3 + 2e- + 6H^+ \longleftrightarrow 2Fe^{2+} + 3H_2O$$

$$MnO_2 + 2e- + 4H^+ \longleftrightarrow Mn^{2+} + 2H_2O$$

(Common in soil where oxygen has been excluded such as in flooded soils.

In seasonally flooded soils (for example the fadama), minerals such as FeOOH and MnO_2 become more soluble and some Fe_{2+} and Mn_{2+} may be removed by leaching).

$$SO4^{2-} + 8e- + 8H^+ \qquad S^{2-} + 4H_2O$$

(This reaction occurs in swampy areas with H_2S as the product leading to stinky odour)

NO_{3-} + 2e- + $2H^+$ NO_2 + H_2O

N_2O + 2e- + $2H^+$ N_2 + H_2O

(Nitrite is more toxic than NO_{3-}, H2S) is more toxic than $SO4^{2-}$ and Fe^{2+}, Mn^{2+} can cause phytotoxicity in rice paddy).

In the absence of any other electron acceptors H^+ (protons) can serve as electron acceptor in the aqueous system.

H^+ + e- ½ H_2

Electrons donors (reducers) in soils.

Dead and decaying organic materials and soil organic matter constitute the electron donors and soil organic matter. Organic matter and plant material denoted by the formula (CH2O)n for carbohydrate yield a half reaction of oxidation as follows

CH_2O C^{4+} + H_2O + 4e- (1)

And the other half-reaction would be

O_2 + 4e- $2O_2$- (2)

With oxygen acting as electron acceptor

The overall reaction is:

$CH_2O + O_2 \longleftrightarrow CO_2 + H_2O$ + energy

Inorganic electron donor in soil include ammonia, hydrogen sulphide and ferrous iron

$Fe^{2+} = Fe^{3+} + e-$

$NH_3 = N^{3+} + 3H^+ + 6e-$

In the reaction ($NH_4^+ + 2H_2O = NO_2^- + 8H^+ + 6e-$)

$H_2S = S^{6+} + 2H^+ + 8e-$

In the reaction ($H2S + 4H_2O = SO4^{2-} + 10H^+ + 8e-$)

Environment Effects of Fertilizer use

Fertilizers are soil amendments applied to promote plant growth. Fertilizers could be classified into two:

Organic: derived from composted plant and animal remains

Chemical or Inorganic: Chemical compounds made in factories

When nutrients and other pollutants associated with animal manures and commercial fertilizers are not managed properly, they can affect plant and animal life negatively.

- Positive effects of fertilizer use on the environment:
  - Soil

  Most soils found in subtropical and tropical areas of the world where majority of the people live are deficient in essential nutrients. Inherent nutrient supplies commonly will allow only 2 – 3 years economic cropping followed by 20 – 30 years bush fallow. These soils can be notably improved by the introduction of fertilizers. Fertilizer use benefits the environment by reducing the pressure to convert forests and other fragile lands to agricultural uses.

  Effective fertilizer use retards Erosion: A well fertilized soil supporting a thriftily growing crop is much less erosion prone in sloping positions than a corresponding soil supporting a poor crop. This crop that enjoys adequate nutrition through fertilizer application will have:

  - Greater surface canopy which will prevent the soil against wind and water action
  - More prolific root system which leads to a greater binding action on soil particles to prevent them from water and wind erosion.

- The residual effects of the greater organic production are significant too, in the improved soil aggregation imparted by the larger quantity of fresh organic return.

- Air
    - Fertilization promotes air purification
      Living plants aid in air purification by absorbing carbon dioxide from the atmosphere for use in the photosynthesis of carbohydrates and the release of oxygen. Stimulated vegetative production with the aid of fertilizers clearly means more fresh air for mankind. This is a bonus considering the increasing amounts of carbon dioxide that man's ever increasing activities are releasing to the atmosphere.

    - Other air contaminants such as SO_2 and NH_3 are additionally absorbed from the air in proportion to the total crop growth. A more luxuriant growing crop with adequate essential nutrients will better scrub the atmosphere of contaminants than a starving plant.

- Crops
    - The mineral, protein and vitamin contents of crops may be improved by judicious fertilization.

- Negative effects of fertilizer use on the environment:
    - Water:
        - Eutrophication: This is the process by which a body of water acquires a high concentration of nutrients especially nitrates or phosphates. Eutrophication results in:
            - Increased production of phytoplankton and algae
            - Reduced light penetration into the water which occurs as a result of increased algae growth. This in turn decreases the productivity of plants living in the deeper waters that are important for producing oxygen.
            - Dissolved oxygen depletion caused by reduced deep-water zone plant life, this could result in the death of desirable fish that require concentrations of dissolved oxygen.
            - Water may become cloudy and discolored
            - Increased costs of water purification if used for human consumption
            - Degrades the aesthetic qualities of surface water bodies
        - Effects of excess nitrate in water: Excess nitrate in water and vegetable leads to high nitrate intake on human health. Nitrates may be reduced to nitrite in the intestinal tract which is then absorbed into the blood stream. Babies below a certain age may be unable to detoxify this nitrite which combines with heamoglobin to give methaemoglobin known as blue baby syndrome which

reduces the capacity of blood to transport oxygen. In adults, nitrite ingested may be converted to nitrosamines which could cause some health hazards.

- Soil:
  - Soil acidification
    - Nitrogen containing inorganic and organic fertilizers can cause soil acidification an example is ammonia, which besides supplying nitrogen can increase soil acidity (lower pH).
    - Heavy metal accumulation
      Industrial wastes recycled into fertilizers can contain toxic metals e. g. lead, arsenic, cadmium and mercury.
    - Radioactive element accumulation
      Uranium is often found in phosphate fertilizers, this may build up to unacceptable levels and build up in vegetable produce if excess fertilizer is applied. Tobacco derived from plants fertilized by rock phosphate contains Polonium-210 which emits alpha radiation estimated to cause about 11,700 lung cancer deaths each year worldwide.
- Atmospheric Effect
  Methane which is a potent green-house gas emissions from crop fields are increased by the application of ammonium based fertilizer, these emissions contribute greatly to global climate change.

  Storage and application of some nitrogen fertilizers in some weather or soil conditions can cause emissions of nitrous oxide (N_2O) which is the third most important greenhouse gas after carbon dioxide and methane. It has a global warming potential 296 times larger than an equal mass of carbon dioxide and it also contributes to stratospheric ozone depletion.

  Green-house gas emissions come about through the use of:

  - Animal manures and urea which releases methane, nitrous oxide, ammonia and carbon dioxide in varying quantities depending on their form (solid or liquid) and management (Collection, storage, spreading)
  - Fertilizers that use nitric acid or ammonium bicarbonate, the production and application of which results in emissions of nitrogen oxides, NO_2, NH_3 and CO_2 to the atmosphere. NH_3, CH_4, CO_2, NO_2 potentially contribute to green-house effect or global heating because of their increasing concentration in the atmosphere and to the destruction of the stratosphere ozone layer which protects the earth from ultraviolet radiation.

➢ Causes of inappropriate Fertilizer Use
Inappropriate fertilizer use may result from:

    - Farmers not following recommended agronomic practices
    - Application of fertilizer at the wrong rate, wrong time and in the wrong way.
- Fertilizer Management Practices which reduce negative environmental effect
  Nitrogen: Identify the correct nitrogen rate required to maximize yield. Significant nitrate accumulation occurs when applied nitrogen rate exceeds that required for optimum yield.

  Timing: Split applications are recommended rather than single applications.

  Placement: Subsurface application of nitrogen fertilizers will reduce N volatilization losses.

  Phosphorus management Practices: P rates applied should not exceed soil P test.

  Placement: Subsurface P placement reduces P susceptible to runoff compared to surface application. As the time interval between application and incorporation increased, potential runoff- P loss increases. Incorporation within 2 – 3 days after application is recommended.

  Timing: Applications during periods of low rainfall may reduce runoff. Phosphorus application just prior to rainfall event can lead to significant P losses in runoff.

SOIL ORGANISMS

The soil is a very complex medium where many chemical, biological,biochemical, geochemical, biogeochemical and physical processes take place.

The soil is also the medium where plants obtain most of their nutrients.

The soil has a vast population of living organisms including micro and macro flora, micro and micro fauna, insects etc.

The activities of some of these organisms are detrimental to plants, particularly the disease causing organisms.

The activities of most are however beneficial to crops particularly with regards to soil aggregation, nutrient cycling, biological nitrogen fixation, nutrient uptake, disease control/prevention and production of growth hormones.

These organisms interact with one another in the soil giving rise to diverse relationships/interactions such as symbiosis, parasitism, commensalism, protocooperation, neutralism, competition.

The soil microorganisms constitute the highest populations of soil organisms and because of their enzymatic capabilities, they are more important in soil processes than other soil organisms.

Classification of Soil Microorganisms

Soil microorganisms can be classified based on physiology or nutrition, mode of respiration and origin

A. Physiological/Nutritional Classification: Microorganisms need food as sources of energy to enable them carry out their activities, for growth and multiplication. Microorganisms differ in their nutrition requirements, whereas some organisms can use the same source of food as carbon and energy, others require different sources as carbon and energy.

On this basis microorganisms are divided into

a. Autotrophs/Lithotrophs: These are organisms that can use CO_2 as the sole source of carbon.

Based on the source of energy they are further classified as;

i. Photoautotrophs/Photolithotrophs: These are organisms deriving their energy from sun through the process of photosynthesis. Such organisms contain a pigment known as chlorophyll which enable them convert CO2to carbohydrate in the presence of sun energy eg Algae.

ii. Chemoautotrophs/Chemolitotrophs: These are organisms which derive their energy from carrying out biochemical oxidations. These organisms release energy from the reactions eg oxidation of NH_4^+ to NO_2^- and NO_2^- to NO_3^-, oxidation of H_2 to H_2O, Oxidation of S to H_2S and $H_2SO_3.^-$

$NH_4^+ + 1^1/_2O_2$ --- $NO_2^- + 2H^+ + H_2O$ *Nitrosomonas sp*

$NO_2^- + H_2O$ --- $NO_3^- + 2H^+$ *Nitrobacter sp*

b. Heterotrophs: These are organisms that organic compounds as their carbon and energy source. They derive both carbon and energy from the same source. Most of the microorganisms belong to this class, in addition to carbon other nutrients like N, K, P, Na, Mg, Ca, Fe, etc which they need are obtained from organic matter.

B. Classification Based on Respiration: Based on mode of respiration, soil microorganisms can be classified as aerobes, anaerobes and facultative anaerobes.

Aerobes: These organisms require free oxygen for their respiration they cannot survive in the absence of oxygen. Most bacteria, all fungi and actinomycetes fall into this class.

Anaerobes: These organisms can grow optimally only in the absence of molecular oxygen, this group incorporates many bacteria eg *Clostridium*.

Facultative Anaerobes: These organisms can survive either in the presence or absence of oxygen. Although they need oxygen, they do not necessarily need to have access to molecular oxygen. They can survive by extracting the required oxygen from an oxygen rich compound such as nitrates or sulfates, the compounds are reduced thus changing their availability to plants.

C. Classification Based on Origin of Microorganisms: Based on their origin bacteria are classified as;

Autochthonous or Indigenous microorganisms: These are the original residents in the soil, their numbers are constant, they do not usually respond to additions of organic matter and they grow very slowly. They may have developmental stages used to endure in soil for a long period without being active metabolically.

Allochthonous or Zymogenes or Invaders: These miroorganisms develop under the influence of specific soil treatemts such as addition of organic matter, fertilization or aeration. They do not contribute significantly to soil processes.

Transient Microorganisms: These microorganisms are introduced into the soil intentionally eg Rhizobium sp, mycorrhizal fungal or unintentionally eg through diseased plants. They die rapidly or may survive in the soil for a period of time in the presence of host plant or animal

BACTERIA

These are unicellular organisms without organelles or nucleus they are one of the simplest forms of life.

The size ranges from 1-5 microns. The shape vary from cocci (round shaped), to bacilli (rod shaped) and to spiral.

In terms of population they probably the most numerous microbes whose population range from a few hundreds to 3 billion per gram soil.

They are very versatile in their metabolic activities some can use simple inorganic materials as enery source while other are heterotrophic. Some bacteria need oxygen for their respiration others are anaerobic and some can adapt to presence or absence of oxygen.

Importance:

1. Bacteria are very important in the general decomposition of organic matter in soil
2. They carry out specific functions important in nutrient cycling such as nitrification
3. A group of bacteria are important in in nitrogen fixation- conversion of atmospheric nitrogen to plant available forms.
4. Some soil bacteria cause diseases

Growth Conditions: Bacteria can survive under diverse environmental conditions.

Optimum pH condition for bacteria growth is slightly acidic to neutral, however some groups survive under highly acidic conditions and they are termed **acidophilic bacteria**.

The optimum temperature range for most bacteria is 25 to 35^{o}C and these are termed **mesophiles**, however, some are able to tolerate extreme temperatures these are **Psychrophiles** (0 to 20^{o}C) and **Thermophiles** (40 to 65^{o}C).

FUNGI

They have well developed organelles including nuclei, mitochondria, they are more developed than bacteria.

The most important characteristic of fungi is the possession of a filamentous body consisting of strands of hyphae. The mycelium can be sub-divided into cross-wall called septa, however there many non-septate fungi.

They about 5 µm in diameter the population range between 0.1 – 1 million propagules per gram of soil

Almost all fungi are heterotrophic in nature and all are aerobic thus they do not occur in diverse environment as bacteria.

Importance:

1. Fungi are important in decomposition of organic residues in soil
2. They are especially important in decomposing woody material which many bacteria cannot decompose.
3. They are important in processes leading to humus formation
4. They play important roles in the formation of stable aggregates
5. Some soil fungi cause plant and animal diseases
6. Some fungi form symbiotic association with roots of higher plants.

ACTINOMYCETES

Structurally, these organisms lie between bacteria and fungi, they bear similarity to bacteria in terms of cell size and structure characteristic and they are filamentous organisms like fungi.

They are the next populous in soil after bacteria, the number ranging from 10^5- $4x10^6$ cell/g of soil

The organisms prefer moist and well aerated soil. They are sensitive to acidic condition, optimum pH ranging from 6 – 7.5

Importance

1. They are important in decomposition of organic matter, especially cellulose, chitin and phospholipids
2. Some actinomycetes produce antibiotics eg *Streptomyces sp*
3. Some actinimycetes cause plant diseases eg potato scab disease.

ALGAE

These are sub-divided into twogroups:

1. Green algae (True algae)
2. Blue-green algae (Cyanobacteria)

Morpologically, the true algae have nucleus, cell wall compose mainly of cellulose and chloroplast distributed within the various organelles.

The blue-green algae do not possess nucleus, cell wall compose of a substance call muramic acid. They have a blue pigment called Phycocyanin distributed throughout the cytoplasm.

Nutritionally, algae are autophototrophic.

Importance

1. Some algae are capable of nitrogen fixation, these can be especially important in some ecological condition eg rice paddies.
2. They form symbiotic associations with fungus (lichens) and fresh water fern (azolla). Lichens are important in early stages of pedogenesis while azollas are important in fertility management of rice paddies

NEMATODES

These are of microscopic size they are like worms round and spindle-like in shape.

The importance of nematodes in soil is not all that related to soil fertility but that some are pathogenic to some agricultural crops. They usually infect the roots of such plants thereby interfering with normal physiology and obstructing water and nutrient uptake. The plants infected are mostly horticultural crops like tomatoes, carrots, ornamental and fruit trees.

EARTHWORMS

These are the first known larger animals in the soil. They thrive best in moist soil with abundant supply of organic matter.

They are very important in the fertility of the soil because they aid in humus formation by in jesting some organic debris and later egesting same as worm cast. The worm cast usually contains high amounts of organic matter, N, Ca, Mg and P.

Earthworm help in the process of soil formation by building new top soil every year. Study has shown that earthworms contribute about 2 cm thick layer of soil every ten years.

Earthworm is also important because of the burrowing activities the channels they leave behind are very effective in surface drainage and aeration.

Earthworm also helps to improve soil water infiltration thereby preventing erosion.

TERMITES

The presence of termites is one of the characteristics of most tropical soils. Termites exhibit very great diversity in their feeding habits; some feed on organic residues, some on wood and some cultivate fungi in their nest.

There are different forms of termite nests, some build huge nests about 3 meters in height and 12 meters in diameter.

The population of nests per hectare can be very high, in some cases they can make up to 20 % of the landscape and as many as 3,000 per hectare especially during rainy season.

Importance: This is under physical, chemical and pedological aspects of the soil.

Physical Effects:

1. They carry only finer particles, thereby leading to increase in the finer structure of the soil.
2. The mound materials are more stable and better aggregated than the surrounding soil thus affecting the structure of the soil.
3. Because of the numerous underground channels they create, the bulk density of the soil is reduced.
4. Also because the mound contains finer particles like clay and high organic matter, the water holding capacity is increased.

Chemical Effects:

1. The soil pH is higher in the mound material because of accumulation of $CaCO_3$.
2. Organic matter is higher than in adjacent soil.
3. The termite mound contain higher amount of Mg, P, Ca and K, thus important in soil fertility.

Pedological Effect:

1. The activities of termites in bringing finer particles from the sub-soil to the surface contribute to formation of gravel and soil free horizon.
2. Up to 560 kg per hectare per year of soil materials can be turned over through the activities of termites, thus helping in soil formation.
3. It has been shown that activities of termites lead to the formation of 3 cm thick of soil every 100 years.

MICROBIOLOGY OF THE RHIZOSPHERE

The microbial population is altered both quantitatively and qualitatively by the presence of plant roots. The microorganisms that respond to the presence of root is distinctly different from other soil community, the plant creates a habitat for organisms. In turn the plant is highly affected by the populations it stimulated since the root zone is the site from which inorganic nutrients are obtained and through which pathogens must penetrate. Consequently, interaction between the macro and microorganism in this region has considerable effect on crop production and soil fertility.

Rhizosphere: The rhizosphere is not a well define or uniform part of the soil, instead it represents a poorly defined zone with a microbiological gradient in which the maximal effect of root and microorganism is in the soil nearest to the root. Outer-rhizosphere and inner-rhizosphere had been used to define zones of influence. The inner-rhizosphere is the root surface and its adhering soil and can be refered to as **rhizosplane**. While the outer rhizosphere beyond this zone but still under the influence of the plant root is referred to as **rhizosphere**. The rhizosphere is a region of highly favourable habitat for the proliferation and metabolism of numerous microbial types. A vast microbial community occursnear and on the surface of roots and root hairs. Bacteria are found to be localized in colonies and chains of individual cell, Fungi and actinomycetes are observed but not as frequently as bacteria. The **rhizosphere effect** is measured quantitatively by the **R/S ratio**. This is defined as the ratio of microbial numbers per unit weight of rhizosphere soil R, to the number in a unit weight of adjacent non-rhizosphere soil. The rhizosphere effect is usually greater for bacteria than other soil microorganisms.

Influence of Plant on Microorganism: The microbial population is affected in many ways by the growing plant, and microbial reactions important to fertility are more rapid in the root environment.

1. The most important contribution to the rhizosphere microorganisms is provision of excretion products and sloughed-off tissue to serve as a source of energy, carbon, nitrogen, and growth factors.
2. Plants assimilate inorganic nutrient within the rhizosphere and therefore lower the concentration available for microbial development
3. Microorganisms are affected by root respiration which alters the pH or the availability of certain inorganic nutrients by the evolution of carbon dioxide.
4. Root penetration improves soil structure and brings about aeration for microbial development.
5. In the presence of nitrates denitrification may result in the root region thus increasing release of nitrous oxide and nitrogen gas.
6. The presence of certain plants, reduce the population of nitrifying microorganisms.
7. The cellulolytic organisms increase in number in response to availability of large quantity of cellulosic tissues in the sloughed-off plant materials and the product of their metabolism provide carbonaceous substrates for other organisms.
8. Some root excretions aid the germination of the resting structures of several fungi by providing them with sources of energy. This stimulus to germination is particularly important to plant pathogens that are not vigorous competitors and remain in the resting stage because of nutrient shortage or fungistasis.
9. Roots may liberate antimicrobial agents, in some instances these are antifungal substances. The production of high quantity of carbon dioxide may inhibit germination or affect fungi in other ways.

Influence of Microorganisms: The microorganisms in the rhizosphere may have either favourable or detrimental influence on plant development. Since the microflora is so intimately related to the root system any beneficial or toxic substances produced can cause an immediate and profound response.

1. Microorganisms may favour the growth of higher plant by affecting the availability of various nutrient elements essential for plant growth, most especially carbon, nitrogen and phosphorus.
2. The production of CO_2 in the rhizosphere and the formation of organic or inorganic acids aid in the solubilization of inorganic plant nutrients. This is particularly so with insoluble phosphate containing compounds.
3. At the same time, the vast population of microorganisms demands some anions and cations for their own development leading to immobilization of N and P.
4. Aerobic bacteria remove O_2 from the environment and add CO_2 and either of these processes may reduce root elongation and development or diminish the rate of nutrient and water uptake.
5. Microorganisms may favour plant growth through the production of specific growth stimulating or growth regulating substances such as auxins and phytohormones egindoleacetic acid, gibberelins and cytokinnins.
6. Some microorganisms are parasitic to plants or produce certain toxic substances which are injurious to plants.
7. Antibiotics may be produced in the rhizosphere and this may affect the growth of root pathogens and even the development of diseases in the above tissues if translocated to stem and intravascular system. Antibiotics are also known to affect the physiology of plant.
8. Some groups of microorganisms form symbiotic relationship with higher plant, eg certain fungi formmycorrhizal association with higher plants and the numbers of free living nitrogen fixing organisms are quite high on the root surface.

MYCORRHIZA

This is the symbiotic association between fungi and root of higher plants, the association is beneficial to most organisms. Mycorrhizas are classified into several groups.

Ectomycorrhiza: This association consists of septate fungal cells infecting roots of trees and shrubs. The fungi form compact mantle or sheath over the root surface and penetrate between the cells of the root cortex to form a complex intercellular system called the Hartig net. The ectomycorrhizal fungi produce auxins responsible for some morphological differences between mycorrhizal and nonmycorrhizal roots. Many fungi from classesBasiodiomycetes, Ascomycetes, Zygomycetes and Mushrooms form ectomycorrhiza. It is usually difficult and sometimes impossible to plant seedlings of trees in grassland soils or other new areas, particularly in forest establishment without introduction of the fungi partner.

Ectendomycorrhiza: This is similar to ectomycorrhiza except that the external mantle of fungi sheath may be much reduced or absent, the Hartig net is well developed and the hyphae also penetrate the host cells.

Ericaceous mycorrhizas: These include the mycorrhizas associated with Arbutus,Ericales and Monotropaceae.

Arbutoidmycorrhizasare formed as mantle which serve as storage organ, when Hartig net is present it penetrates the outer layer of the cortical cells. The septate hyphae form intracellular coils that eventually disintegrate within the cell.

Ericoid mycorrhiza occurs between the ericaceous plants and a fungus called *Pezizella*. The fungus formsmultiple coils within the cells and up to 42 % of the root cells can be occupied by the fungal hyphae.

MonotropoidMycorrhiza: A member of the Basidiomycetes called *Boletus* infects both the monotropa and the roots of neighboring trees. The seed of monotropa is very small it will initiate germination but will not develop further until infected with *Boletus*. Phosphate and glucose can be translocated by the fungi over a distance of 1 to 2 m to the tissue of monotropa.

Orchidoidmycorrhizas: Orchid seedlings are very small and the seedlings pass through a seedling stage during which they are unable to photosynthesize. Since the seeds are too small to contain reasonable reserves, a germinating embryo does not develop further unless it receives an outside supply of carbohydrates or is infected by a compatible mycorrhizal fungus. The infection in orchids spreads from cell to cell, with hyphae coils taking up a large portion of the volume of infected cells. The intracellular hyphae have a limited live and degeneration can occur as early as 30 to 40 hours after initiation of infection and is usually complete within 11 days. Fungi genera involve include *Rhizoctonia*, *Marasmius*, *Armillaria* and Fomes. Parasitism of host plant can occur as in monotropoidmycorrhizas.However unlike monotropoidmycorrhizas, a Hartignet, well developed fungal sheath and specialized haustoria are absent.

Arbuscularmycorrhizal fungi (AMF): These are the most common forms of mycorrhizasit involves fungi classified as Zygomycetes. The aseptate hyphae infect the root cells of nearly all cultivated plants, forest trees, shrubs and herbaceous species. No visible structural change is observed on the root except on onion where a sight yellowing of the root is observed. Internal vesicles constituted by fungal hyphae expansion filled with lipids are used for storage. There is another internal structure in the root cortex called arbuscule, this consist of finely branched hyphae and persist within the plant cell for 4 to 10 days. After which they are digested by the plant cell and new ones are formed in other cells. Nutrient transfer occurs between the finely branched fungal mycelium and plant cell membranes. Some fungihyphae and resting spores extend externally in the soil. Five major genera of the family Endogonaceae form AMF, these are; *Glomus*, *Gigaspora*, *Acaulospora*, *Sclerocystis* and *Scutellospora*. They are distinguished by the morphology of their resting spore.

FUNCTIONS OF MYCORRHIZAS

1. The major contribution of the fungus is in nutrient uptake and translocation, especially of phosphorus and sometimes nitrogen.
2. Mycorrhizal plants have the capacity to withstand or tolerate drought better than non-mycorrhizal plants.
3. The plants are protected from pathogens, nematodes and heavy metal concentrations in the rooting zone.
4. The fungi partners obtain carbon from the plant.

5. Mycorrhizal fungi have aggregating effect especially on coarse soil.
6. The production of phyto-hormones such as cytokinins may have positive effect on plant growth.

BIOLOGICAL NITROGEN FIXATION

Nitrogen fixation is the conversion of atmospheric nitrogen to plant available nitrogen. It can be brought about by electrical discharge (lightning) or other ionizing phenomena of the upper atmosphere (Haber process). The fixed nitrogen is added to the soil as a component of precipitation.

200 atms

N_2 + $3H_2$ ----------------------- $2NH_3$-------- NH_4OH

450^oC, Catalyst

Most of the nitrogen fixed into the soil is however accomplished by biological nitrogen fixation. There are two types of biological nitrogen fixation; Symbiotic nitrogen fixation and Non symbiotic nitrogen fixation.

Non Symbiotic nitrogen fixation

This biological nitrogen fixation is carried out by organisms which live freely in soil as represented by two groups of microorganisms; bacteria and blue-green algae (cyanobacteria).

Bacteria genera involve in nitrogen fixation could be aerobes, facultative anaerobes and anaerobes

Examples of aerobic bacteria include, species of *Azotobacter* and *Beijerickia*

Examples of facultative anaerobe include species of *Bacillus.*

Examples of anaerobe include species of*Clostridium*

For the blue-green algae, the examples include species of Nostoc, Plectonema and Anabaena.

These nitrogen fixers add between 0.2 and 5 kg N/ha/annum, whereas most crop plants require 50 – 200 kg N. This process is therefore thought to be of little significance agronomically. However, the process is of value in rice paddies where blue - green algae, which depend on photosynthesis freely, fix nitrogen. The process is highly influenced by the population of nitrogen fixers in the soil and this in turn is dependent on soil pH.

Symbiotic nitrogen fixation

This is the production of plant available N from atmospheric nitrogen by organisms that live in association with plant roots. These bacteria reside in the roots of legumes causing swellings known as nodules in legume roots. They derive their food and nutrients from the legumes and in turn supply the legumes with nitrogen fixed from the atmosphere. This symbiotic relationship is most common between legumes and *Rhizobium* species. Examples of legumes include trees such as *Acasia, Mimosa and Cassia*,shrubs such as *Ceasalpina* and *Indigofera* as well as crops such as cowpea, soybean, groundnut, pigeon pea, etc. The Rhizobium species are host specific and when the right species are not present in the soil, where the legume is grown, nodulation may not occur and even when some nodules are formed nitrogen fixation may not occur at all or at significant level. Therefore, under certain conditions Rhizobium inoculation is recommended.

Grain legumes are capable of fixing about 150 kg N/ha/annum, an amount that meets the nitrogen requirement of many crop plants.

Mechanism of nitrogen fixation

The central reaction according to which biological nitrogen fixation proceeds and the enzyme responsible for the reaction are the same in all organisms (Symbiotic and non-symbiotic). $N_2 + 6e^- + 8H^+ + 12ATP$ ---------- $2NH_4 + 12ADP + 12pi$

A molecule of nitrogen gas reduced to ammonia requires energy to proceed. It is estimated that 12 moles of ATP are required for 1 molecule of N_2, which is reduced to 2 molecules of ammonium.

The enzyme responsible for nitrogen fixation is called **Nitrogenase**. It consists of two proteins (i) Iron protein also called Azoferredoxin or Component II or Azofer (ii) Molybdenum iron protein also called molybdo-ferredoxin or Component I or Azofermo. The individual component does not catalyse any reaction only the combined system of both proteins is regarded as an enzyme.

Both of thenitrogenase proteins are Iron-sulphur components. The iron protein is the smaller of the two with molecular weight ranging from 50,000 – 70,000. It is rapidly but reversibly inactivated by oxygen. The molecular weight of molybdenum iron protein range from 100,000 – 300,000 and also reversibly inactivated by oxygen

Factors influencing nitrogen fixation

Biological factors

1. There has to be appropriate organism-host relationship or compatibility,because not all rhizobia can form nodules in all legume roots.
2. The plant should be nutritionally healthy to carry out optimal photosynthesis so as to obtain enough carbon for itself and the organism.
3. Infection by other organisms should be minimal, eg infection of roots by nematodes.

Chemical factors

1. High soil nitrogen content discouragesnitrogen fixation.
2. Soil pH has a profound influence on the process, soil pH of 6 – 7.5 favour nitrogen fixation.

Physical factors

Aeration is important as most of the organisms involved are heterotrophic and aerobes. However, the presence of oxygen could retard the process, since it is a reduction process.

The presence of a pigment called **Legume haemoglobin** salvages the problem by binding O_2 thereby rendering it inactive, to be released only when needed. A cross section of an active nodule is reddish brown due to the presence of legume haemoglobin.

Agronomic importance of nitrogen fixation

1. In symbiotic nitrogen fixation the organisms live inside plant root, nitrogen fixed is immediately assimilated into products needed by plants such as amino acids, amines etc. In non-symbiotic fixation, the nitrogen is fixed into soil and absorbed by plants.
2. When ploughed in as green manure or incorporated as crop residues, the nitrogen synthesized into organic N can be mineralized as nitrates and be of benefit to crops that will be subsequently grown in the soil.
3. In mixed cropping, when legumes and non-legumes are grown in mixture, the non-legume benefit from nitrogen fixed by legumes.
4. Nitrogen fixation is so important that where it is suspected that the appropriate strains of rhizobia are not present in the soil, legume seeds are inoculated with such strains.

Relationship between Rhizosphere and Soil Microorganisms

The term "**rhizosphere**" denotes the region of the soil which is subject to the influence of plant root. The word, "rhizosphere" comes from *rhizo* or *rhiza* which is a Greek word for root, and sphere which denotes an environment or area of influence. The rhizosphere is the zone of soil surrounding a plant root where the biology and chemistry of the soil are influenced by the root. This zone is about 1 mm or a few millimeters wide, but has no distinct edge. It is usually characterized by greater microbiological activities than the soil away from plant root due to the food supply provided by the release of varieties of materials (exudates and secretions) which include alcohol, ethylene, sugar, amino and organic acids, vitamins, nucleotides, polysaccharides, mucilage, proteins and enzymes. The exudates act as messengers that stimulate biological and physical interactions between roots and soil organisms.

The plant root surface known as the rhizoplane also provides unique environment for microorganisms, as these gaseous, soluble and particulate materials move from plant to the soil. Rhizoplane is more narrowly defined and it describes the surface of the plant root itself along with the tightly adhering soil particles. The practical definition of rhizosphere soil is that soil which adheres to or is influenced by the root but which can be removed from the root by gentle shaking in sterile water.

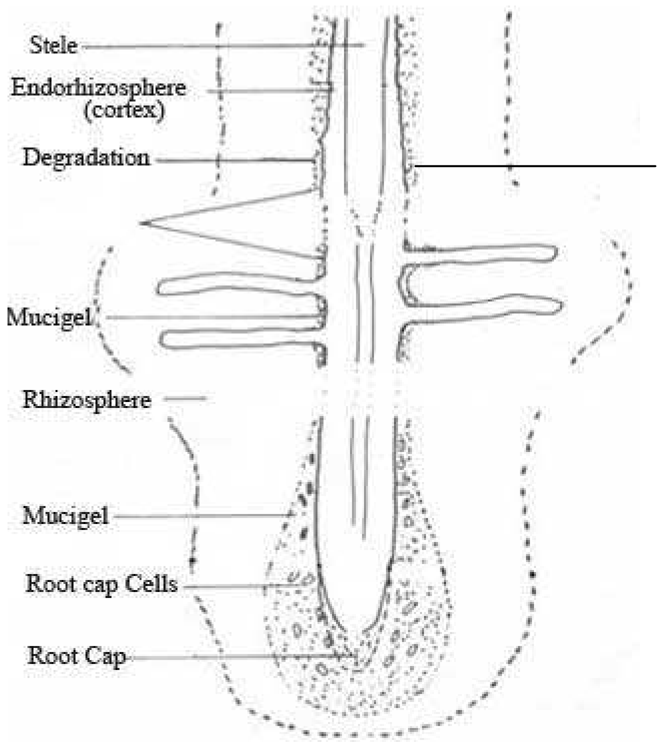


Figure 1**.** Diagram of a root showing the rhizosphere

Because of the unique environment created in the rhizosphere for microorganisms, various microbial processes occur in the zone. These processes may be beneficial or non-beneficial. Some microorganisms form different associations with the plant roots while others are free living, taking advantage of the unique environment of the rhizosphere to provide certain benefits for plants. Beneficial relationships between soil microorganisms and rhizosphere occur in the process of nitrogen fixation in soils. Nitrogen fixation is a biochemical reduction of atmospheric nitrogen (N_2) to ammonia. Nitrogen fixation in rhizosphere occurs through symbiotic association of some bacteria and plant roots or a non-symbiotic association of some free living bacteria (associative N fixation). Mycorrhizal association is another beneficial relationship between soil microorganisms and plant roots, helping plants in acquisition of some nutrients especially phosphorus.

Associative Nitrogen Fixation

This is a non-symbiotic but associative process of nitrogen fixation by some microorganisms which inhabit the surface of plant (rhizoplane) as well as the rhizosphere. Certain nitrogen fixing bacteria establish themselves close to the root in the rhizosphere where they use root exudates, secretions and sloughed cells as an energy source and fix nitrogen into the soil. The extent of rhizosphere-associated N fixation depends on the supply of oxidizable C and efficiency of its conversion. The amount of nitrogen fixed by these microorganisms is indirect, as 90% of the nitrogen only becomes available when the bacteria die. Associative N fixation is carried out by representatives of the genera of *Azotobacter*, *Azospirilum* and *Acetobacter*. These bacteria contribute to N accumulation in tropical grasses e.g an association between *Azotobacter paspali* and a grass plant called *Paspalum notatum*.

Symbiotic N_2 fixing association between legume and rhizobium

Symbiosis denotes the cohabitation of two unrelated organisms which mutually benefit from the close association. In the case of N fixation, the invasion of root of the host plant by a microorganism (endophyte) culminates in the formation of a nodule in which carbohydrates are supplied to the endophyte and amino acids formed from the reduced N are made available to the host plant.

Several genera of root nodule bacteria exist in rhizosphere. These include *Allorhizobium, Azorhizobium, bradyrhizobium, Mesorhizobium, Sinorrhizobium* and *Rhizobium.* Rhizobium is well known to establish a symbiotic association with legumes and fix nitrogen for the use by plant. Rhizobia exist primarily as soil saprophyte that are widely distributed and are found in the rhizosphere of plant roots. The bacterium contains a large plasmid that encode information that is not used when it grows as a free living organism in soil but its vital for infection and nodulation of the susceptible host plant. Plasmid encoded gene also influences the range of host plant that rhizobium can nodulate.

The establishment of mutualistic relationship between rhizobia and legumes is accomplished via a series of developmental stages, all of which are mediated by physiological signal from both participants. This symbiotic process is highly specific (i.e a specific bacterial species with one, or a limited number of, legume species). One *Rhizobium* strain can infect certain species of legumes but not others e.g. the pea is the host plant to *Rhizobium leguminosarum* biovar *viciae*, whereas clover acts as host to *R. leguminosarum* biovar *trifolii*. Specificity genes determine which *Rhizobium* strain infects which legume. Soybean has a specific symbiotic partner; it is only nodulated by *Bradyrhizodium japonicum* and this species nodulates only soybean. However, some promiscuous (nodulate with many rhizobial strains) soybean or legume species exist.

At each stage of the formation of this relationship, the chemical signals released by the plant and the bacterium reciprocally induce unique genetic program that lead to the formation of a nodule and result in biological N fixation.

Root nodule formation

Sets of genes in the bacteria control different aspects of the nodulation process. The rhizobial genes that are needed to establish a symbiosis with plant root are called **Nod genes**. These genes are involved in the synthesis and transport of an unusual class of compounds referred to as **nod factors** that induce nodule formation. Nod genes also direct the various stages of nodulation. The initial interaction between the host plant and free-living rhizobia is the release of a variety of chemicals by the root cells into the soil. Some of these encourage the growth of the bacterial population in the area around the roots (the rhizosphere). Reactions between certain compounds in the bacterial cell wall and the root surface are responsible for the rhizobia recognizing their correct host plant and attaching to the root hairs. Flavonoids secreted by the root cells activate the nod genes in the bacteria which then induce nodule formation. The plant genes that are exclusively involved in the early stages of root-hair infection and nodule development are called **nodulin** genes.

The whole nodulation process is regulated by highly complex chemical communications between the plant and the bacteria. Once bound to the root hair, the bacteria excrete nod factors. These stimulate the root hair to curl. Rhizobia then invade the root through the hair tip where they induce the formation of an infection thread. Infection threads are tubular structures that carry the rhizobia often in single file, from the point of entry into root hairs to the inner cells of the root cortex. This thread is constructed by the root cells and not the bacteria and is formed only in response to infection. The infection thread branches and penetrates into the root cortex, where cortical cells divide and enlarge to form a prenodule in response to the rhizobial invasion. Rhizobia are released from the infection thread into root cortical cells and are enclosed within plant-derived membrane called the peribacteroid membrane. They remain physically isolated from the host cell cytoplasm. Each membrane-enclosed bacterium is referred to as a "symbiosome". The bacteria continue to produce nod factors which stimulate the root cells to proliferate, eventually forming a root nodule. Within a week of infection, small nodules are visible to the naked eye. Each root nodule is packed with thousands of living *Rhizobium* bacteria, most of which are in the misshapen form known as bacteroids. The rhizobia undergo pleiomorphic and biochemical changes in the symbiosome (contains bacteroids) and ultimately commence biological N fixation

An enzyme called **nitrogenase** catalyses the conversion of nitrogen gas to ammonia in nitrogen-fixing organisms. In legumes it only occurs within the bacteroids. The reaction requires hydrogen as well as energy from ATP.

Root nodules differ in appearance and structure depending upon the host plant species. Nodules may be spherical, cylindrical, flattened or irregular in shape. There may be some 10^{10} bacteriods in a nodule, generally containing a single strain of rhizobium although multiple-strains occupancy does occur. Strains of rhizobia which form nodules on a legume are termed infective. Those strains which then proceed to fix nitrogen at high rate are termed effective and those which are poor nitrogen fixer are termed ineffective. Effectiveness is governed by a different set of genes in the bacteria from the specificity genes.

Actinorhizae

Actinorhizal relationship is the association of actinobacteria (actinomycetes) with plant roots. These symbiotic associations are formed between bacterial genus ***Frankia*** and many non-leguminous plant species widely distributed among eight different families which are commonly referred to as actinorhizal species. The actinorhizal plants tend to be woody shrubs or trees and are usually in the primary stages of recovery from some disturbances such as wildfire, flood, logging and landslide. They are also pioneer species on site poor in nitrogen. Well known actinorhizal plants are *Alnus* (Alder), *Myrica* (bayberries), *Casuarina, Eleaeganus, Ceanothus, Hippophae* and *Purshia.* The actinorhizal relationship has energy cost to plant, however the plant does benefits and is better able to compete in nature. Unlike the small nodules formed by rhizobium in legume roots, the nodules of actinorhizal plants may be several centimeters in diameter, some are marble sized while some are as big as soccer ball size.

Nitrogen fixation and agriculture

Nitrogen fixation by rhizobia is of great importance in agriculture in several ways. Legumes such as peas, beans and soybeans, help to feed the meat-producing animals of the world as well as humans. Crop yields are greatly improved in nodulated plants. Legumes can also grow well in poor soils where there is not enough fixed nitrogen to support other types of plants. After harvest, legume roots left in the soil decay, releasing organic nitrogen compounds for uptake by the next generation of plants. Farmers take advantage of this natural fertilization by rotating a leguminous crop with a non leguminous one. Nitrogen fixation by natural means cuts down on the use of artificial fertilizers. This does not only saves money but helps to prevent the many problems brought about by excessive use of commercial nitrogen and ammonia fertilizers such

Mycorrhizae

Mycorrhiza is the mutualistic symbiosis between soil borne fungi and roots of higher plants. The word was coined by Frank (1895) to describe the union of two different organisms to form single morphological organ in which the plant nourishes the fungus and the fungus the plant. The host plant provides the fungus with soluble carbon sources, and the fungus provides the host plant with an increased capacity to absorb water and nutrients from the soil.

Based on the physical association of mycorrhizal fungi with plant roots, two main types are distinguished;

1. Ectomycorrhizae
2. Endomycorrhizae

These two were further subdivided into seven kinds by Smith and Read (1997): (1) Arbuscular mycorrhizas (AM), (2) ectomycorrhizas, (3) ectendomycorrhizas, (4) arbutoid, (5) monotropid, (6) ericoid, and (7) orchid mycorrhizae.

Ectomycorrhiza

Ectomycorrhizal fungi form symbioses with several gymnosperm and angiosperm species and belong to the Phylum Basidiomycota and Ascomycota. In ectomycorrhiza, arbutoid and monotropid mycorrhiza, infection may arise from existing mycorrhizal roots which act as point inoculum sources. Mycelia fan out into soil and when they contact an uninfected root hyphae aggregate to form strands or mantle over the surface of the root. Hyphae penetrate the root and proliferate within the intercellular space forming a Hartig net.

Arbuscular mycorrhiza

Arbuscular mycorrhiza (AM) is probably the most widespread terrestrial symbiosis. It is formed between obligate biotrophic fungi of the phylum Glomeromycota and roots of around 80% vascular plants. The name arbuscular is derived from the characteristic structures, the arbuscles, which occur within the cortical cells. Arbuscular mycorrhiza has three important components; the root itself, the fungal structures (arbuscles, vesicles, intraradical hyphae and spores) within the cells of the root and extra radical mycelium in the soil. The AM symbiosis initiates when fungal hyphae, arising from spores in the soil or adjacent colonized roots contact the root. The colonization process includes arrival of the fungus at the root, penetration and development of the infection, and its spread to other parts of the root. Formation of an appressorium (a swollen structure formed on the end of a spore germ tube in contact with the root) often occurs as a prelude to infection. Hyphae then penetrate the epidermal cells or pass between these cells and penetrate the outer cortical cells. Some of the important genera of AMF are *Glomus, Paraglomus, Gigaspora, Acaulospora, Entrophospora* and *Scutellospora*. Unlike ectomycorrhiza, AM are non cultivable outside host plant. However, their internal structure can be observed in clear and stained root sample under light or stereo microscope.

Benefits of mycorrhizae

1. **Enhanced nutrient uptake**. This is achieved by the expansion of zone of nutrient uptake farther away from the rhizosphere and more efficient uptake and transport of nutrients. Phosphorus nutrition is greatly enhanced by AM colonization. Arbusclar mycorrhizal plants generally grow better in phosphate deficient soils than non mycorrhizal plants. All type of mycorrhizal fungi are able to transport N and P.
2. **Improved tolerance to water stress.** Mycorrhizae increase the effective absorptive surface area of the plant.
3. **Disease tolerance in crop**. mycorrhizal plant root tends to be colonized by fewer disease-causing organisms
4. **Improvement of soil structure**. Mycorrhizae create conditions that are conducive for the formation of soil micro-aggregates and macroaggregates. In addition, AM fungi produce glomalin, a specific soil-protein, present in soil in large amounts and is considered to stably glue hyphae to soil to form a ‘sticky’ string-bag of hyphae which leads to the stability of aggregates.

Biodegradation of Pesticides

Pollutants

A pollutant is anything that degrades the quality of something else. It can be liquid gas or solid material and could have been useful in the past or be a by- product or residues from the production of something useful. Some pollutants are natural materials that either get in wrong place or become too concentrated in some places e.g soil becoming a pollutant by getting into water or air (dust).

Pollution occurs when substance are released into in environment in harmful amount as a direct result of human activity.

Pollutants can be classified into three types

1. those substances that occur in nature but as a result of human activity are found in unusually large concentrations e.g. CO_2, elevated CO_2 concentration in the atmosphere is affecting the climate.
2. toxic substances that are produced by human and does not occur in nature e.g pesticides
3. substances which are themselves not toxic but as a result of human activities have unfortunate consequences e.g. effect of certain substances on the ozone layer

Apart from pesticides, other common pollutants in soil and agricultural fields are heavy metals, high concentration of some plant essential nutrients, oil spills etc.

Pesticides

Pesticides are the chemical substances that kill pests and weeds. In the context of soil, pests are fungi, bacteria insects, worms, and nematodes etc. that cause damage to field crops. Thus, in broad sense pesticides are insecticides, fungicides, bactericides, herbicides and nematicides that are used to control or inhibit plant diseases and insect pests. Pesticides include one or more elements such as arsenic, boron, bromine, cadmium, carbon, chlorine, copper, fluorine, hydrogen, iron, lead, magnesium, manganese, nitrogen, oxygen, phosphorus, sodium, sulphur, tin and zinc. The benzene ring is quite frequently found in pesticisde. It is a six carbon ring with six hydrogen atoms indicated as hexagonwith double bond. When other groups have replaced one or more of the hydrogens, the ring is referred to as the phenyl radical rather than benzene radical. When other group attached with two benzene ring, it is referred to as diphenyl e.g DDT

Although wide-scale application of pesticides and herbicides is an essential part of augmenting crop yields; excessive use of these chemicals leads to the microbial imbalance, environmental pollution and health hazards. An ideal pesticide should have the ability to destroy target pest quickly and should be able to degrade to non-toxic substances as quickly as possible.

Many pesticides are chemically similar to several others and are therefore given family names such as chlorinated hydrocarbons or organic phosphate. Pesticides that can be decomposed readily are biodegradable, whereas those that resist decomposition are called persistent. The properties that commend a chemical as an effective pesticide, namely

a. broad spectrum of activity so that it controls more than one pest and
b. sufficient persistence at the site of application so that the frequent retreatment is unnecessary

can be detrimental to the ecological balance of the whole environment.

Pesticides reaching the soil in significant quantities have direct effect on soil microbiological aspects, which in turn influence plant growth. Some of the most important effects caused by pesticides are:

(1) alterations in ecological balance of the soil microflora.

(2) continued application of large quantities of pesticides may cause ever lasting changes in the soil microflora.

(3) adverse effect on soil fertility and crop productivity.

(4) inhibition of N_2 fixing soil microorganisms such as *Rhizobium*, *Azotobacter*, *Azospirillum* etc. and cellulolytic and phosphate solubilizing microorganisms.

(5) suppression of nitrifying bacteria, *Nitrosomonas* and *Nitrobacter* by soil fumigants ethylene bromide, Telone, and vapam have also been reported

(6) alterations in nitrogen balance of the soil.

(7) interference with ammonification in soil.

(8) adverse effect on mycorrhizal symbioses in plants and nodulation in legumes.

(9) alterations in the rhizosphere microflora, both quantitatively and qualitatively.

Persistence of pesticides in soil

Persistence of pesticides refers to how long an insecticide, fungicide, or herbicide persists in soil. It is of great importance in relation to pest management and environmental pollution. Persistence of pesticides in soil for longer period is undesirable because of the reasons such as

a) accumulation of the chemicals in soil to highly toxic levels,

b) assimilation by the plants

c) accumulation in the edible portions of the root crops and other plant products,

d) pollution of soil, water and air.

The effective persistence of pesticides in soil varies from a week to several years depending upon structure and properties of the constituents in the pesticide and availability of moisture in soil. For instance, the highly toxic phosphates do not persist for more than three months while chlorinated hydrocarbon insecticides (eg. DOT, aldrin, chlordane etc) are known to persist at least for 4-5 years and some times more than 15 years.

From the agricultural point of view, longer persistence of pesticides leading to accumulation of residues in soil may result into the increased absorption of such toxic chemicals by plants to the level at which the consumption of plant products may prove deleterious / hazardous to human beings as well as livestock's. For example, intensive use of DDT to control insect pests and mercurial fungicides to control diseases in agriculture had been known to persist for longer period and thereby got accumulated in the food chain leading to food contamination and health hazards. Therefore, DDT and mercurial fungicides has been, banned to use in agriculture as well as in public health department.

Process of biodegradation of pesticides in soil

Although physical and chemical factors are important in the biodegradation of pesticides, microorganisms play a major role. Many soil microorganisms have the ability to act upon pesticides and convert them into simpler non-toxic compounds. This process of degradation of pesticides and conversion into non-toxic compounds by microorganisms is known as “biodegradation”. Not all pesticides reaching to the soil are biodegradable and such chemicals that show complete resistance to biodegradation are called “recalcitrant”.

The biodegradation of compounds of pesticides is often a complex series of biochemical reactions and is often different when different microorganisms are involved. The particular details of each biodegradation scheme are not particularly important, but the general series of reactions and enzyme types involved are relatively straightforward.

Two major mechanisms are involved in pesticides degradation. In the first, pesticides are degraded by the organisms with **specific enzymes** which usually provide nutrient or energy benefits to the organism. In the second form of degradation, pesticides are degraded by the metabolic pathways which exist for other purposes i.e. pesticides compound is metabolized alongside the normal functioning of the cell virtually by accident, the process known as co-metabolism.

Biodegradation of pesticides and pollutants by soil microorganisms involves a process known as mineralization whereby microorganisms convert the organic molecule to obtain C and energy for growth and multiplication releasing inorganic form of nutrients or elements. In the process the parent molecule becomes detoxicated by enzymatic reaction. Complete or partial detoxication of pollutant or pesticide compound can occur through processes such as hydrolysis, dehalogenation, demethylation, methylation, nitro-reduction, deamination, cleavage of ether linkages, conversion of nitrile to amide and conjugation.

The chemical reactions leading to biodegradation of pesticides fall into several broad categories which include

a) Detoxification: Conversion of the pesticide molecule to a non-toxic compound. Detoxification is not synonymous with degradation. Since a single change in the side chain of a complex molecule may render the chemical non-toxic.

b) Degradation: The breaking down or transformation of a complex substrate into simpler products leading finally to mineralization. Degradation is often considered to be synonymous with mineralization, e.g. Thirum (fungicide) is degraded by a strain of *Pseudomonas* and the degradation products are dimethlamine, proteins, sulpholipids, etc.

c) Conjugation (complex formation or addition reaction): In which an organism make the substrate more complex or combines the pesticide with cell metabolites. Conjugation or the formation of addition product is accomplished by those organisms catalyzing the reaction of addition of an amino acid, organic acid or methyl crown to the substrate, for e.g., in the microbial metabolism of sodium dimethly dithiocarbamate, the organism combines the fungicide with an amino acid molecule normally present in the cell and thereby inactivate the pesticides/chemical.

d) Activation: It is the conversion of non-toxic substrate into a toxic molecule, for eg. Herbicide, 4-butyric acid (2, 4-D B) and the insecticide Phorates are transformed and activated microbiologically in soil to give metabolites that are toxic to weeds and insects.

e) Changing the spectrum of toxicity: Some fungicides/pesticides are designed to control one particular group of organisms / pests, but they are metabolized to yield products inhibitory to entirely dissimilar groups of organisms, for e.g. the fungicide PCNB fungicide is converted in soil to chlorinated benzoic acids that kill plants.

Factors affecting biodegradation of pesticides

Biodegradation of pesticides is greatly influenced by the soil factors like moisture, temperature, pH and organic matter content, in addition to microbial population and pesticide solubility. Optimum temperature, moisture and organic matter in soil provide congenial environment for the break down or retention of any pesticide added in the soil. Most of the organic pesticides degrade within a short period (3-6 months) under tropical conditions. Metabolic activities of bacteria, fungi and actinomycetes have the significant role in the degradation of pesticides.

The chemical structure of pesticides seriously affects its degradation. Most synthetic pesticides are heavily substituted with either chlorine, bromine, fluorine, nitro or sulphonate groups in structures which are not found in biological tissues. Pesticides may be recalcitrant because of the shape of structure where these halogens and nitros are substituted. The higher the level of substitution the more the recalcitrant the compound e.g. 2,4-D (2,4-dichlorophenoxyacetic acid) is much more readily decomposed than 2,4,5-T (2,4,5-trichlorophenoxyacetic acid) and certain substitutions e.g. substitution at the meta position on an aromatic ring convey more recalcitrance than ortho or para substitution.

Criteria for Biodegradation
For successful biodegradation of pesticide in soil, following aspects must be taken into consideration.

i) Organisms must have necessary catabolic activity required for degradation of contaminant at fast rate to bring down the concentration of contaminant,

ii) the target contaminant must be bioavailable,

iii) soil conditions must be congenial for microbial or plant growth and enzymatic activity

iv) cost of bioremediation must be less than other technologies of removal of contaminants.

It has been stated by some scientists that for every naturally occurring organic compound there is a microbe or enzyme system capable of its degradation.

Composting

Composting is the biological decomposition of wastes consisting of organic substances of plant or animal origin under controlled conditions to a state sufficiently stable for storage and utilization. The composting process imitates the decomposition of organic matter on the surface layer of the soil to turn raw manure into humus. It is an active process of converting biodegradable organic wastes to stable humus through the action of microorganisms such as bacteria, fungi and actinomycetes, which are widely distributed in nature. The major objectives in composting are

1. to stabilize putrescible organic matter
2. to conserve as much of the plant as nutrient and organic matter as possible
3. to produce a uniform, relatively dry product suitable for use as manure

The product of composting activities is known as compost. Practically, any plant or animal material can be composted. However, yard wastes, poultry manure and other livestock wastes, wood sawdust and crop residues are the common compost materials.

Waste materials such as leaves, root and stobbles, crop residues, straws, hedge clippings, weeds, water hyacinth, bagesse, sawdust, kitchen wastes and human habitation wastes undergoes intensive decomposition under medium-high temperature in heaps, windrows or pits with adequate moisture. In about 3-6 months, an amorphous brown to dark brown humified material called compost is obtained.

Factors affecting composting

1. C:N ratio of the materials used for composting
2. Water content of the materials
3. Aeration
4. pH
5. Temperature
6. particle size

7. Prevalence and succession of microbial population

An important factor that affect composting and its product is the C:N ratio of the starting material which ideally should be 25 to 30:1. Different materials have different C:N ratio depending on the make up of the material. Materials such as wood and sawdust have very high C:N ratio while materials such poultry manure, grass clippings, soil humus have low C:N ratio. The table below shows the C:N ratio of some materials used in composting.

Materials	C:N ratio
Grass clippings	12 – 15
Manure	20 – 50
Poultry manure	15
Activated sludge	6
Vegetable waste	12
Wheat straw	80
Sawdust	200 – 500
Wood	400

Composting can be classified as either aerobic or anaerobic. Anaerobic decomposition results in only a partial breakdown of organic matter and is generally associated with a disagreeable odour. Adequate aeration is essential in aerobic composting because it aids the action of aerobic organisms that are involved in the process. Oxygen level of 10 – 18% should be maintained.

Water content of the material is important in aerobic decomposition. To achieve optimum aerobic decomposition, the water content of the organic material should be between 50 and 60% on wet weight basis. This level of water content provides a condition for microorganisms to act optimally in the process of decomposition.

Temperature and pH are also key factors in composting and a strong relationship exists between these two factors. Temperature and pH do not only determine the rate of decomposition in composting but also the prevalence and succession of microorganisms involved. The relationship between temperature and pH changes with time. During the early mesophilic stage, pH decreases to about 5 and fungi are the dominant organisms because they can tolerate acidic condition. However, as temperature of the composting mass increases (thermophilic stage), there is a corresponding increase in pH, and bacteria and actinomycetes are most active. The maximum pH rises to about 8.0, sychronised with the temperature peak during the thermophilic stage. Thereafter, pH usually levels off at values above 7.0. High temperature may lead to loss of nutrient especially N, therefore it is better to keep the temperature below 60 C.

Composting configuration

Composting configuration refers to the physical management of the process such as the use of piles, stacks, or windrows. Configurations range from windrow or open systems to enclosed systems, with windrow further classified as either static or turned.

Process strategy in composting

Process strategy in composting refers to the management of the biological and the chemical activity of the composting process. In the biological process, four stages are identified. These are

1. Active stage which refers to the mesophilic phase
2. High rate stage which refers to the thermophilic stage
3. Controlled stage which refers to the cooling phase
4. Curing stage which refers to the maturing phase.

The process of composting cannot be completed without these four stages which starts from the active stage and ends with the maturing stage. These stages influence the kind of microorganisms that are involved in composting.

Advantages of composting

1. Compost supports and encourages the growth of earthworms, bacteria, fungi and other micro-organisms and adds organic matter to the soil. In this way, compost improves the biological, physical and chemical properties of the soil.

2. Composting increases the pH of the material which can help make the soil a better environment for plant growth.

3. The composting process stabilizes the volatile nitrogen of raw manure into large protein particles and thereby reduces losses.

4. Compost returns nitrogen, phosphorous, potassium, calcium, magnesium and the micronutrients back to the soil.

5. The nutrients from mature compost are released to the plants slowly and steadily. The benefits will last for more than one season.

6. The nature of the material and the fungal or actinomycetes mycelia contained in the compost and stimulated in the soil by its application help to bind the soil particles into crumbs, greatly increasing the stability of the soil to wind and water erosion.

7. Compost has a lower density, 400-600 kg/m^3 compared with typical manure that may be 400-1000 kg/m^3. Handling is easier and fewer trips are made to the field.

8. Odour is reduced.

9. Weed seeds are reduced by a combination of factors including the heat of the compost pile, rotting and premature germination.

10. Fly eggs are killed and plant and animal pathogens are reduced if the high heat method of composting is used to raise the temperature of the pile to 60°C.

11. Raw manure is one of the primary culprits for pollution of the waterways, and odour from farms is considered an increasing problem in the rural areas. Composting raw manure reduces these problems.

Further Reading

1. Soil Microorganism by N. Walker
2. Introduction to Soil Microbiology by Martin Alexander
3. Soil Microbiology and Biochemistry by E. A. Paul and F. E. Clark
4. Effects of Intensive Fertilizer Use on the Human Environment. Food and Agriculture Organization of the United Nations, Rome, 1978.