COURES CODE: *SOS 519*

COURSE TITLE: *Soil Ecology and Biology*

NUMBER OF UNITS: *2 Units*

COURSE DURATION: *Three hours per week*

COURSE DETAILS:

Course Coordinator: Dr. (Mrs) Oluwatoyin.A. Babalola *B.Sc, M.Sc. PhD*
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Other Lecturers: Dr. C.O. Adejuyigbe and Dr. M. O. Dare

COURSE CONTENT:

Soil microorganisms and macroorganisms. Microorganisms and soil enzymes. Microorganisms and plants. Root-nodule bacteria. Mycorrhizal relationships. Plant regulators and phytotoxins. Soil macrofauna. Agricultural systems and microorganisms; rhizoshere; root exudates and microorganisms; plant residue quality; organic farming; composting. Biological transformation; N, P and S. soil biotechnology: biofertilization by rhizobial and mycorrhizal fungal inoculation; genetically modified plants and microbes and their ecological effects. Biodegradation of pesticides.

Practical: culturing microorganisms; Root samples and preparation for mychorrizal studies; Root nodules; identification and analysis of N. microarthropods in soil and litter; extraction methods, classification and population dynamics. Earthworm; extraction methods, classification and population.

COURSE REQUIREMENTS:

This is a compulsory University course. In view of this, students are expected to participate in all the course activities and have minimum of 70% attendance to be able to write the final examination.

READING LIST:

Ruiz N and P Lavelle, 2008. *Soil Macrofauna Field Manual*. Food and Agriculture Organisation (FAO), Rome

Muller-Samann K. M. and J. Kotschi (1994). Sustaining Growth: Soil fertility mamagement in tropical smallholdings. ICTA; GTZ. Margraf Verlag 486p.

Soil Microbiology, Ecology, and Biochemistry (2007). Edited by Paul E.A. 3rd Ed. Academic Press, Elsevier.

Subba Rao N.S. (1999) Soil Microbiology. 4th Edition of Soil microorganisms and plant growth. Oxford & IBH, New delhi

LECTURE NOTES:

SOIL MICRO AND MACROORGANISMS

The free living components of soil biota are bacteria, actinomycetes, fungi, algae as well as the micro and macrofauna. Additionally, there is viruses which grow only within the living cells of other organisms.

Viruses

Viruses consist of RNA and DNA molecules within protein coats. Viral particles are metabolically inert and do not carry out respiratory or biosynthetic functions. They multiply only within the host and induce a living host cell to produce the necessary viral components, after assembly, the replicatedviruses escape from the cell with the capability of attacking new cells.

Importance of viruses

1. Their ability to interact with host genetic material can make viruses very difficult to control.
2. This is also the reason why they are useful as genetic transfer agents in genetic engineering because they can serve as transfer agents a wide diversity of cells.
3. Viruses are distinguished by their ability to pass through filters capable of holding all known bacterial types.
4. They have capability for self-reproduction and ability to cause many plant and animal diseases. Viruses infect all categories of animals and plants from humans to microbes.
5. Viruses that infect soil organisms can persist in soil as dormant units that retain parasitic capability.
6. The ability of viral particles pathogenic to plants and animals to survive in soil and move into the water table is a major concern.
7. Viruses have promising prospect in biological control of weeds and obnoxious insects.

Bacteria

Bacteria are the most numerous of the microorganisms in soil. Indeed they are the most common of all the living organisms on the face of the earth. They lack nuclear membranes therefore they are termed prokaryotic cells. Their cell walls are composed principally of peptidoglycans and reproduction is by binary fission. Genetic transfer is accomplished by conjugation and transduction.Energy source and carbon source are useful for describing physiological differences among bacteria and other organisms. The majority of known bacterial species is chemoorganotrophic and is commonly referred to as heterotrophs and a few species are chemolitotrophs. The obligate chemolitotrophs used the same physiological pathway i.e Calvin cycle. Their inability use any known external source of organic carbon is linked to lack of permeases to move organic molecules across cell membranes. Therefore organic molecules must be manufactured within the cell.

The following are some bacteria which are prominently encountered in the soil taking part in soil processes.

Arthrobacter:

Numbers of the genus are numerically prominent in soil constituting up to 40 % of the total plate count population. They are reported to utilize 85-180 compounds. They are slow growing and poor competitors in the early stages of decomposition when easily decomposable materials are rapidly attacked by other genera.

Pseudomonads:

They are aerobic except for denitrifying species that use nitrate as an alternative electron acceptor. Most species are organotrophs, a few are facultative litothrophs using H_2 or CO as an energy source. They also occur in marine waters, some species cause plant disease, and many nonpathogens are closely associated with plants. They attack a wide variety of organic substrate including sugars, amino acids, alcohol and aldose sugars, hydrocarbons, oils, humic acids and many of the synthetic pesticides.

Xanthomonas:

This is closely related to *Pseudomonas*, it embraces similar properties ecept that molecular oxygen is the only electron acceptor and nitrates are not reduced. They are pathogenic to many plants.

Sporulating Bacilli:

These members of the genus Bacillus produce heat resistant endospores and sporulation is not repressed by exposure to air. They are mostly vigorous organotrophs and their metabolism is strictly respiratory, strictly fermentative or both. There is great diversity within the genus as shown by the array of products formed by different species during the course of glucose fermentation, products include; glycerol, 2,3-butanediol, ethanol, hydrogen, acetone and formic, acetic, lactic and succinic acids. Some species are facultative litotrophs that use H_2 as an energy source in the absence of organic carbon. *Bacillus polymyxa* is able to fix nitrogen. Several species produce lytic enzymes and antibiotic that are destructive to other bacteria eg *Bacillus thuringiensis* produce toxin which is pathogenic to insect lavae. *Bacillus mercerans* is used for retting flax, *Bacillus anthracis* is a highly animal pathogen.

Clostridium:

This is a sporogenic genus, most are strict anaerobes. The genus is of economic importance used commercially for the production of alcohols and commercial solvents. Several species such as *C butyrichum* and *C pasterianum* fix nitrogen. They are widely distributed in soils, marine and freshwater sediments, manures and animal intestinal tract. Some species are pathogenic to animals, eg *C tetani* and *C butilinum*.

Azotobacter:

This is an aerobic organotrophic bacterium capable of fixing nitrogen asymbiotically. Other genera fixing nitrogen asymbiotically are Azomonas, Beijerinkia, Dexia and Azospirillum. And Rhizobium are known to fix nitrogen symbiotically. A related genus Agrobacterium induces galls on hairy root but does not fix nitrogen. *Nitrosomonas* and *Nitrobacter* are chemolithotrophic genera. *Nitrosomonas* convert NH_4^+ to NO_2^- and *Nitrobacter* convert NO_2^- to NO_3^-.

Lactobacillus:

This is a fermentative organotrophic bacterium; it is commonly associated with plant herbage. Its lactic acid production is exploited in silages, butter, milk and local dairy products. *Enterobacter* is also fermentative found in animal feces and sewage; some species are widely distributed in soil.

ACTINOMYCETES

About 90 % of the actinomycetes isolated from soil belong to the genus Streptomyces. Its members produce a well-developed, compact branched mycelium and compact colonies on agar plates. Reproduction is by production of aerial spores and by mycelial fragmentation. They are intolerant of waterlogged soil, less tolerant of dessication than fungi and generally intolerant of acidity. Thus causal organism of potato scab *S scabis* is controlled in poorly buffered soils such as sand by sulphur and ammonium amendment which result in lowered soil pH.

Many Streptomyces produce antibiotics, antibacterial, antifungi, antialgal, antiviral, antiprotozoal, or antitumor. Streptomyces also produce geosmin which is responsible for the musty smell of freshly plowed soil and partly responsible for the musty smell of earthen cellers and old straw piles. It appears that Streptomyces is mainly responsible for the maintenance of soil biological balance.

FUNGI

These are the eukaryotic organisms variously referred to as mold, mildews, rusts, smuts, yeasts, mushrooms and puffballs. Fungi are the organotrophs primarily responsible for decomposition of organic residues even though they are always outnumbered by bacteria. Important classes encountered in soil include;

Aerasiomycetes:

These are unicellular; the unit of structure is the uninucleate amoeba that feeds by engulfing bacteria. Single cells characteristically aggregate into pseudoplasmodium in which the cell does not fuse but behave as a mobile communal unit, this later change into a fruiting structure called sporocarp which bears the asexual spores.

Myxomycetes:

These are true slime forming asexual creeping plasmodium, they are animal like in their feeding but fungus like in their reproductive structure and spore formation. They are widely distributed especially in association with decaying vegetation in cool moist locations.

Oomycetes:

They are found in water and soil, they are highly destructive to plant, and they produce biflagellate asexual motile spores called zoospores. *Pythium* and *Phythophthora* are commonly encountered in soil.

Chytridiomycetes:

They are prevalent in aquatic habitat, but also commonly encountered in soil, some members are parasitic on algae, higher plants or insect lavae.

Zygomycetes:

They ferment different carbohydrate substrates. They are mostly saprobic, but some are phytopathogenic, some parasite on other fungi, some produce animal trapping mechanisms. The mucorales which are the largest order are important economically as they are used for commercial production of alcohol and organic acids.

Ascomycetes:

Ascomycetes and Basidiomycetes are called the higher fungi. The ascomycetes are distinguished by the formations of ascus within which are ascospores following sexual reproduction. Many of them are saprophytic having a range of impacts eg plant pathogenicity, some are destructive on materials. Others are beneficial eg the fermenting activities of yeast which has long been exploited in beer, wine and bakeries.

Basidiomycetes:

This include a wide selection of fungi, they differ from other fungi by the production of specialized structure called basidium. Many of them are plant parasite thus causing heavy losses of crop and tree plants. Some are beneficial eg mycorrhizal-forming relationship with plants; mushroom has commercial importance as edible food. They are vigorous decomposers of woody materials.

Deuteromycetes:

This embraces fungi with septate hyphae but reproduce only by means of conidia, they do not have a sexual reproductive phase, and they are called fungi imperfecti. They are mostly saprobic in soil, some may be parasiticon other fungi, higher plants, humans and other animals eg species of *Aspergillus, Penicillium, Trichoderma, Fusarium*.

ALGAE

Blue green algae

Cyanobacteria are the blue green algae they possess photosystem II and carry out oxygenic photosynthesis. They contain chlorophyl A and phycobiliprotein pigments such as phycocyanin. They exist in unicellular, colonial and filamentous forms. They have single cells, reproductive cells or units and filamentous forms enclosed in rigid sheaths and they often show gliding motility. They are widely distributed occurring in saline and fresh waters, in soil, on bare rocks and sand. They also occur within the plant bodies of some liverworts, water ferns and angiosperms. In some ecosystems cyanobacteria are of great significance because of their ability to fix nitrogen.

Green algae

These are the eukaryotic algae they are the simplest forms of the chlorophyllus eukaryotes distinguished from other green plants by sexual characteristics. Some green algae are unicellular and some are multicellular. The algae are the most widely distributed of all green plants. They are predominantly aquatic found in fresh, brackish and salt waters. Terrestrial forms occur on rocks, mud and sand, snowfields and buildings and attached to plants and animals. Subsurface soil samples kept moist and under illumination commonly develop algae blooms. Most algal units found below ground are dormant forms some are however known to be facultative organotrophs.

SOIL MICROFAUNA

These are the microfauna (less than 0.1 mm), mesofauna (0.1-10 mm) and macrofauna (greater than 10 mm)

Microfauna

This is typified by the protozoans, they are unicellular most of which are microscopic in size but some attain macroscopic dimensions. The group is greatly diverse in morphology and feeding habit. All require water envelopment for metabolic activity. Five main groups are commonly recognized; Flagellates, ciliates, naked and testate amoeba and sporozoa. Sporozoans are wholly parasitic. Free living protozoa in soil feed on dissolved organic substances and other organism. Many feed by grazing and predation, the soil ciliates depend primarily on bacteria for food, some feed additionally on yeasts and other protozoa and even on small metazoan such as rotifers. The soil an effect on the structure and functioning of microbial communities, the rise in bacteria numbers following addition of fresh residues to soil is always followed by a rise in protozoan numbers. Selective feesding by protozoa may alter the mix of bacterial genera. Protozoa may accelerate nutrient cycling and their active motility in the soil water help to provide bacteria with dissolved oxygen and nutrients.

Meso and Microfauna

These are also called metazoan, they include; the soil dwelling nematodes, millipedes, centipedes, rotifers, mites, annelids, spiders and insects. The small members exemplified by nematodes are able to move through existing soil pores without disturbing the soil particles. The nematodes are also called are the most numerous of the soil metazoan, their numbers may reach several million per square meter. The free living forms in soil are voracious feeders on both microflora and other fauna. Earthworms constitute the major portion of the invertebrate biomass in soil and when present are active in processing litter distributing organic matter throughout the soil. The importance of the mesofauna in soil lies in its effect on soil and litters and on the structure of microbial communities.

SOIL ENZYMES

Life is composed of a series of enzyme reactions and most of the reactions in the nutrient cycle are catalyzed by enzymes. Some enzymes are constitutive and are routinely produced by cells eg. Urease, others are adaptive or induced formed only in the presence of susceptible substrate or other initiator eg. cellulase is produced in the presence of cellulose. Dehydrogenase is constitutive and found only in living systems. Soil enzymes are protein and are often entrapped in soil organic and inorganic colloids. Soil aggregates and their constituent clays are influenced the interaction of enzymes with their substrate. The clay particle with its large external and internal surface areas is capable of adsorbing enzymes such as urease and protease. Enzymes adsorbed to clay or intertwined with humate constituents are protected from hydrolysis. Adsorption also makes the catalytic site less available. A small molecule such as urea can diffuse readily to a urease site and there undergo decomposition. Whereas a large molecule such as protein would not diffuse as readily to a protease site and would be consequently broken down at a much slower rate than urea.

Soil has a large background of extra cellular enzymes not directly associated with the microbial biomass, such enzymes include catalase, dehydrogenase, glucose oxidase, peroxidase, transaminase, cellulose, deaminase, lipase, nucleotidase, phosphatase, phytase, protease, urease etc. Many enzymes however that have utmost significance in soil processes originate from microorganisms eg nitrogenase, nitrate reductase, nitrite reductase etc.

ASSOCIATION OF MICROORGANISMS WITH PLANT

Plants and microorganisms interact with each other and the interaction can be beneficial and sometimes detrimental to either of the partners. Microorganisms are present in the different parts of the plant and in different plants, and influence of plant on microorganism varies depending on the part of plant and the plant. Therefore the association of microorganisms and different plant parts are discussed below.

Association with plant roots

Plant root system occupies the soil horizon most heavily endowed with soil organic matter and life, senescent and dead roots provide substrate materials for microbial growth. The sum total of phenomena occurring at or near the root /soil interface has great impact both on plant welfare and on soil organisms. The number of soil organism at successive distances from the root surface is inversely correlated with increasing distance. For bacteria, higher population occurs within the first 5 µm, fungal hyphae occur on the root surface and strands extend randomly for several millimeters. The sum total of root/microbial interaction is termed **rhizosphere**.

Rhizosphere

This is known generally as the soil region under the immediate influence of plant roots and in which there is proliferation of microorganisms. The recognition that the root surface itself is a critical site for interactions between microbes and plant led to its designation as **rhizosplane**. The epidermal and cortical tissue of roots has been shown to harbor organisms other than symbionts and pathogens. Colonized root tissue is sometimes referred to as **endorhizosphere, histophere** or **cortosphere**. The factor primarily responsible for microbial activity in the three zones is the available carbon contained in or emanating from plant roots.

The R/S ratio i.e ratio of organisms count in rhizosphere soil to count in root-free soil were determined for different plant species and for single species in different soils under differing climatic regimes and at different stages of phenology. Total microbial counts increased from 10-50 folds in the rhizoshpere.

Root exudates

Organic materials found on, in or near roots include a wide assortment of amino, aliphatic and aromatic acids and amides, sugars and amino sugars. In addition to soluble and diffusible substrates is an array of insoluble materials like cellulose, lignin, protein etc. Nearly all plant rhizosphere is expected to contain varying amounts of nearly all the simple sugars, organic acids, and amino acids. Some of the more complex aromatic acids occur only in certain rhizospheres.

Likewise, production of certain microbial attractants and repellants is limited to certain species, for example asparagus plant produse a diffusible glycoside that is toxic to some nematode. Various plants are also known to produce non diffusible compounds that are biostatic or biocidal to saprobes and root invading pathogen. Such phytoalexins include tomatin, allicin, pisatin and phaseolin produce by tomato, onion, pea, and bean plants respectively.

Pathways for the release of plant assimilates from roots include leakage or diffusion of molecules across cell membranes, roots secretion and extrusion and losses of cells and tissue fragments during root growth. Root caps and tips are sites of active exudation of mucilaginous materials, while the main root axis release mostly diffusible materials ans some mucigels.

Root mucigel consists of polysaccharides synthesized intracellularly and extruded through the cell membrane. It is highly hydrated with fibrillar structure and contains carboxyl groups that form bondings with clays. Mucigel is the dominant excretory product of root accounting for up to 80 % of the total carbon loss from roots.

Association with plant shoot

Plants support abundant leaf surface organisms, this association is termed **phyllosphere**. Intensity of colonization is influenced by climatic and plant factors, high humidity favours while insolation disfavor most heterotrophs both factors favour phototrophs. Plant stems and barks are often colonized by algae and liches. Broadleaf plants support more organisms on their leaf surfaces than grasses. G^- and yellow pigmented bacteria dominate the bacteria flora while yeasts dominate the fungal flora.

Nonpathogenic organisms occur within the tissues of fruits, stems and leaves. The coats of seeds prior to release from fruiting structures are sparsely colonized, during dispersal, additional organisms either casual or contaminants or members of the phyllosphere population become seed coat occupant. Some seed associated organisms produce auxins, vitamins and gibberellin-like substances that benefit emergent seedlings. Other organisms are known to produce substances that delay seed germination and others represent plant pathogens.

Association with plant litter

The initial invaders of the aboveground litter are primarily organisms already present in the phyllosphere. Senescent leaves before detachment suffer attack by both microflora and fauna, standing dead wood and branches often lose half their carbon through attack mesofauna and lignolytic fungi before becoming surface litter. As leaves and small twigs or stems fall to the ground the numbers of bacteria there on increases sharply. The bacterial populations of moist litter exceed that of the phyllosphere by two folds. The litter organism varies with depth and with stage of decay. The soil fauna are more active in forest litter than in litters from grassland or cultivated land. Fauna biomass is concentrated in the surface litter and decreases rapidly in the underlying soil.

INFLUENCE OF MANAGEMENT PRACTICES ON SOIL ORGANISMS

Any management practice that changes soil properties or plant cover affects the soil organisms. Practices that affect coil water, temperature, aeration, pH regimes, organic carbon and nitrogen levels will also affect the population and activities of organisms.

Effect of tillage on soil microorganism

Three tillage procedures commonly used are conventional tillage, reduced or minimum tillage and zero tillage. The first employs various mechanical/manual farm implements; reduced tillage involves weed control by machinery, while zero tillage control weed by the use of herbicides, the only soil disturbance is that associated with seed placement. In conventional tillage there is stimulation of microbial activity shown by higher count and increase rate of respiration. This result from disruption of soil aggregates and better exposure and aeration their degradable material. The inversion and fragmentation of surface residues results in a zone of intense microbial activity. By contrast reduced or zero tillage result in microbial activity at or near the soil surface. For the 0-0.75 cm depth counts for total aerobes, facultative anaerobes and fungi are higher in zero tillage than in plowed soil. For 7.5-15 cm depth counts of aerobes, fungi and nitrifying bacteria are significantly reduced in zero tillage.

SOIL FAUNA

Soil biota (living things in the soil, soil organisms) consists of two broad categories – flora and fauna. Soil organisms are a major factor in soil formation and their effects determine many differences between soils. Soil organisms are an integral part of agricultural ecosystems. The presence of a range of a diverse community of soil organisms is essential for the maintenance of productive soils. Soil organisms are responsible for a range of ecological functions and ecosystem services including:

- nutrient cycling and nitrogen fixation,
- control of pest and diseases,
- organic matter decomposition and carbon sequestration,
- maintenance of a good soil structure for plant growth and rainwater infiltration,
- detoxification of contaminants.

Various soil organisms affect certain soil processes in different ways. An excessive reduction in soil biodiversity, especially the loss of species with key functions, may result in severe effects including the long-term degradation of soil and the loss of agricultural productive capacity.

Through their feeding activities, soil fauna play important roles in ecosystem dynamics as they influence the decomposition subsystem and cycling of plant nutrients and other elements that are of environmental importance. Soil fauna as a major group of soil biota are classified based on their sizes, habitat, and feeding form apart from their taxonomic classification. Classification of soil fauna based on their feeding form is also termed functional classification

Soil fauna classification based on sizes

Soil fauna are classified on the basis of their sizes as microfauna, mesofauna and macrofauna. The classification could be based on the body width or body length.

Table 1: Soil fauna classification based on body width

Body width	Class	Examples
< 0.1 mm	Microfauna	Protozoa, nematodes, rotifer,
0.1 mm – 2.0mm	Mesofauna	Mites, Collembola, Protura, Symphyla
2.0 mm – 20.0 mm	Macrofauna	Earthworms, termites, millipedes

Table 2: Soil fauna classification based on body length

Body length	Class	Examples
< 0.2 mm	Microfauna	Protozoa,
0.2 mm – 10 mm	Mesofauna	Nematodes, Mites, Collembola, Protura, Symphyla
> 10 mm	Macrofauna	Earthworms, termites, millipedes

A taxonomic class of soil organisms may also be grouped based on the their sizes. For example, members of the phylum Arthropoda are classified based on their sizes as either microathropods, mesoarthropods or macroarthropods

Different size-groups of soil fauna may also be classified on the basis of their habitat or life form. The habitat and life form of soil fauna are closely related to their ecosystem function. Classification of soil fauna based on their feeding form is also termed functional classification

SOIL MACROFAUNA

Soil macrofauna consists of a large number of different organisms that live on the soil surface, in the soil spaces (pores) and in the soil area near roots. Their way of living, their feedings habits, their movements into the soil, their excretions and their death have direct and indirect impacts on the soil. The biological activities of soil macrofauna play significant roles in soil processes and soil fertility. The effects of soil macrofauna on soil can be divided into three classes: physical, chemical and biological effects. These effects are determined by the functional group involved in the process.

Classification of macrofauna based on habitat or life form

Endogeic: Endogeic species are those that live entirely in the soil and feed on organic matter and dead roots; they may also ingest large quantities of mineral material. The two main groups among soil macrofauna are earthworms and soil-feeding termites.

Epigeic: Epigeic soil fauna live and feed on the soil surface. They play role in litter breakdown and nutrient release. They are mainly arthropods, for example: ants, beetles, cockroaches, centipedes, millipedes, woodlice, grasshoppers, together with gastropods (snails/slugs) and small or medium-sized entirely pigmented earthworms (dark red, green or brown colour, fast movers).

Anecic species: These remove litter from the soil surface through their feeding, redistributing it to other horizons or locations, accompanied by effects on soil structure and hydraulic properties.

Physical Role of Soil Macrofauna

The main activities of soil macrofauna may be grouped into the following

- Soil mixing (macro- and micro-levels)
- Gallery construction,
- Fragmentation,
- Aggregate formation.

Soil mixing at macro-level (macromixing)

This is the movement of notable quantity of soil: bringing back to the surface mineral matters from deeper horizons and burying the organic matter from the surface horizons, from litter and from excrements. Examples of macrofauna involved include ants, termites, earthworms and ground beetles.

Macromixing of soil by earthworms is major activity of importance to soils. It can be measured by the quantity of casts found on the soil surface. Earthworms can produce 40–250 tonnes of casts per hectare per year. Earthworms casts are richer in nutrient content than the surrounding top soil. Some beetles such as the large (*Heliocopris dilloni*) are very efficient at incorporating and removing excrements that are on the soil surface.

Soil mixing at micro-level (micromixing)

This involves mainly the incorporation of organic matter into the soil through the activities of soil surface dwelling macrofuana. For example Diptera larva. With the aid of water percolation, their effect could extend to the depth of 60 cm through leaching. Micromixing is important in influencing soil structure.

Gallery construction

Galleries are tunnel-shaped passages in form of network in the soil. They are formed through burrowing activities of especially earthworms and termites. Gallery formation is very important for

- soil aeration and water flux
- improved soil macro-porosity
- the water-holding capacity of soil
- reduce soil compaction,
- improved water infiltration
- offering new paths for root penetration and leached clays.
- penetration paths for other surface invertebrates with more limited burrowing capacities, e.g. very small earthworms, slugs, insect larvae, and mesofauna.

Litter fragmentation

The fragmentation of dead wood (lignin material), carcass and litter has a major effect on organic matter decomposition in soil. It creates large surface area for the activity of bacteria, fungi and microfauna populations. Fragmentation is performed by phytosaprophagous animals (i.e. animals feeding on decayed plant material and dead animals). Litter fragmentation enhanced decomposition leading to formation of humus

<u>Aggregate formation</u>

Humus formed as a result of the activities of soil fauna act as biding agent for soil mineral particles thus aiding the clumping together of soil particles forming a crumbly healthy structure. Also, earthworms, termites, millipedes, centipedes and woodlice ingest soil particles with their food and contribute to aggregate formation by mixing organic and mineral matter in their gut.

Chemical effects of soil macrofauna

The chemical effects of soil macrofauna on soil include:

- modification of food quality through its passage in the gut,
- mineralization of organic matter and the release of nutrients.
- activation of microflora in the mineralization of N, P and S.

Macrofauna regulates the activity of soil microorganisms through their interactions. Because of their inability to move in soil to search for food, microorganisms are only active when in contact with assimilable substrates (root exudates, earthworm mucus and other materials) that initiates their metabolic capabilities. Microorganisms have a high capacity to digest almost all organic substrates, while macrofauna have the potential for mechanical activities that help bring the microorganisms in contact with the substrates. Hence their interactions are important to soil function.

Biological effects of soil macrofauna

The biological effects of soil macrofauna include

- Maintenance of ecosystem balance through their feeding habits – particularly predation and competition
- Soil environmental sanitation through the activities of **necrophagous** (which feed on dead and/or decaying animals) and **coprophagous** organisms (feeding on dung or excrement) such as Diptera larvae, Coleoptera and Lepidoptera larvae and adults. They clean the soil surface and incorporate organic matter into soil.
- Dissemination of bacteria and spores through excrement dispersion in soils or by on-body transport.

The importance of the functions performed in soils by macrofauna and the physical, chemical and biological changes induced in a soil environment as a consequence of its activity make it a vital part of all ecosystems, including agro-ecosystems. Soil macrofauna is involved in:

degrading organic matter and mineralizing nutrients;

- controlling pathogen populations;
- improving and maintaining soil structure;
- mixing organic matter through the soil.

THE DECOMPOSITION SUBSYSTEM

Organic materials, litters, and residues (mainly of plant origin) are the precursors from which soil organic matter (SOM) is formed through decomposition and synthesis of new materials by soil organisms. Litter or residue quality play important role in the dynamics of soil organic matter in both natural ecosystems (a unit of biological organisation characterised by the integrated and largely self-maintained functioning of a diverse community of organisms with a range of physical environment) and intensively managed agroecosystems. Residue quality affects the rate of litter decomposition, nutrient release, level and quality of SOM. Detrital organic materials represent a bottleneck in nutrient cycling within an ecosystem. Its decomposition leads to release of essential nutrients for plant uptake. The importance of

Plant Residue and Residue Quality

Plant residue quality (PRQ) is a composite definition of the value of the residue as food to an organism. In other words, it is a measure of its decomposability (how easy it can be decomposed). Plant RQ embodies both physical and chemical criteria because both the physical, morphological and chemical attributes of litter determine the rate of decomposition. As food for soil organism, the residue must satisfy the physical (surface properties, texture etc.) and chemical (phagostimulant, growth factor and nutrition) requirements for ingestion or colonisation to occur.

Chemical Determinants of Plant Residue Quality

The chemical composition of plant residues that influence the activities of soil organisms in decomposing the residues may be divided into three main groups of compounds

Carbon and energy source**:** Carbon and energy are required in largest quantity by heterotrophic organisms to fuel their growth and activity. The bulk of the C and energy is stored in a variety of polymeric compounds such as polysaccharides (starch, cellulose, hemicelluloses); lipids; protein; and aromatic polymers such as lignin or humus. The differences

Nutrient sources: These are elements other than carbon (such as N, P, K, etc).

Modifiers: Molecules that inhibit or stimulates decomposer activity by their chemical structure and are often (not always) active at relatively low concentration (e.g. polyphenols).

The concentration of C, N, lignin, polyphenols and their ratios in residues have been used to assess their quality, as well as for predicting nutrient release from the residue. The higher the C/N ratio, lignin content, and polyphenol content of residue the lower the rate of decomposition. In the tropical region, C/N ratio has been found to be the best predictor of N release. Nitrogen release increases with decreasing C/N ratio. When the C/N ratio is less than 30:1, N in litter will be mineralised under normal circumstances. Higher C/N ratio leads to immobilization. Nitrogen concentration can be used to predict N release of plant residue with N concentration <2% while the polyphenol/N ratio can be used for residue with N concentration <1%.

Phytotoxins in soil

Soil microorganisms produce a tremendous variety of organic substances during the decomposition of plant and animal residues, and, as numerous studies have shown, some of these substances are phytotoxic. While certain organisms secrete growth-stimulating substances, others produce growth-inhibiting substances.

COMPOSTING

Composting is the process of deliberate biological and chemical decomposition and conversion of organic or plant refuse and residues for the purpose of producing humified material referred to as compost under controlled conditions.

Importance of composting

Composting and compost application to soil is an effective means of residue management and essential nutrient management especially in tropical environment known for high rate of decomposition and nutrient leaching.

Composting also help the problems associated with the management of plant residues. During the process of composting, high temperature develops which helps in destruction of disease pathogens, pests, weed seeds and viruses. Menace of rodents breeding in scattered litters is prevented by composting plant residues. Composting is a means by which plant nutrients can be recycled with minimized loss because nutrient release from the compost can be synchronised with uptake by crop.

The end product of the composting process is a fertilizer with valuable properties and functions as soil amendment. Compost exhibits all the functions of soil organic matter. It improves both the physical and chemical properties of the soil – cation exchange capacity, soil structure, and soil tilt. It improves water holding capacity and crumb formation, promotes infiltration, protects against erosion and facilitates the spread and penetration of plant roots. Compost stimulates biological activity of the soil.

Compost acts as slow-release fertilizer thereby enhancing effective nutrient cycling. The slow release nature prevents loss of nutrients through leaching and enhances synchronization of nutrient release with uptake by the crop, and a long-term effect on soil fertility unlike other fertilizer sources. Composting products are odourless and easier to handle than the original materials from which the composts are made.

Principles of composting

Composting may be aerobic or anaerobic. In *aerobic composting*, living organisms, organic materials, moisture, ventilation and temperature are essential factors in. During the process of composting, the original structure of the organic materials is attacked by series of different organisms (decomposers) in succession beginning with bacteria, fungi, earthworms, isopods, millipedes and snails, followed by protozoan, collembolans and mites, and later by ants, beetles and predators. Bacteria and fungi are first colonizers while most of the higher organisms help in physical breakdown of the materials.

Composting materials

The chemical composition of the compost materials play significant role in the quality of the compost that is produced. The most important parameter to be considered is the ratio of carbon to nitrogen in the materials. The higher the C/N ratio, the lower the rate of decomposition. The C/N ratio of the compost mixture should not exceed 30:1. To achieve this, a mixture of 75% heterogenic plant refuse and 25% animal manure could be used. If the C:N ratio is low, N would be lost during composting. If the C/N ratio is higher than 35/1, the process will slow down and the optimum temperature will not be achieved.

In general principle, all organic materials are suitable for composting. However, separate treatment is required for feaces of carnivorous animals and excreta of human being.

Temperature

Hot heaps work very fast and efficiently and produce useable compost within short time in contrast to cold heaps. Cold composting methods take very long time and suitable only where little quantity is needed at a time and there is lot of space to make heaps.

Cold composting requires very little maintenance and it allows wider range of organisms. However, cold composting does not kill weed seeds or diseases.

Hot composting helps to maximize production but it requires high maintenance. To achieve sufficient range of temperature in hot heaps, balance of materials is crucial and all the materials have to be added at once. The temperature increases sharply reaching 60^o to 70^o C within the first 3 days, and continues this level for about a day before dropping slowly. The conversion process is most efficient at the hot phase with micro-organisms that thrive at high temperature multiplying while most weed seeds and agents of disease are destroyed.

Size of heap also affects the processes of composting. Too large heap however can overheat, leading to death of almost all the organisms. Turning of compost heap helps either re-enact the hot phase, or reduce built-up of excess heap depending on size of heap. Turning can be done after 2 to 14 days. During turning, materials on the peripheral are move to the centre where the temperature is normally the highest.

Aeration

Insufficient aeration of compost heap leads to death of the aerobic bacteria and anaerobic conversion of materials, rot or silage formation. Adequate air flow ensures fast decomposition and formation of good product. To achieve adequate aeration, materials should be prepared such that they do not stack too loosely or become compacted. No part of the composting heap should be further than 70 cm from the surface. Composting boxes could be made with air holes. Channels for gaseous exchange can be created by inserting post in the centre of the heap. Turning several times at the early stage of decomposition also helps in adequate aeration.

Moisture

Adequate moisture condition is important for the activity of microbial decomposers. At low moisture content (12-15%) the decomposition process stops. Moisture content between 40 and 60 % is ideal. Higher moisture condition may lead to putrefaction or cooking of compost materials at high temperature. Different compost materials require moistening in different ways. While materials like straw may require pre-soaking, soft and weak-structured materials like paper quickly become compacted thus preventing aeration. Layer arrangement of materials can also help out in such situation.

To ensure adequate moisture condition, compost can be constructed under shade, or covered with materials or life mulch (in cold composts), or be done in pit (especially in dry regions or during dry season). To prevent excessive moisture condition during raining season, compost heap can be covered with polythene; solid roof can be constructed over compost heap. Domed heap shape also allows rainfall to drain off.

Composting additives

Under condition of adequate moisture, temperature and aeration, microbial decomposers already present in the compost materials will multiply rapidly without any need for activator. Any substance with low C/N ratio or high level of available energy (such as dung, molasses, neem cake etc.) can serve as a natural activating agent. A little quantity of soil added would also ensure diverse numbers of microbial decomposers from soil organic matter to be involved in the process. However, additives may be added to composting heaps for specific purposes.

In order to avoid P fixation which is very high in tropical soil, phosphate rock of chemical composition recommended in organic farming is better added when required. In the absence of potassium-rich plant wastes, potash feldspar can be added if the aim is to produce compost rich in K.

Sometimes, lime could be added to achieve natural pH progression. In such situation, the lime, or other materials such as gypsum and ashes could be sprinkled thinly over each layer because too much alkali leads to high level of denitrification.

Methods of composting

Composting can be done in small, medium or large scale, depending on size of farm or production system, and availability of resources. However, the same principles apply in any case. Large scale aerobic composting systems tend to come in three main types.

Windrows systems where material is stacked in long piles generally up to 2-3m tall (or even higher when mechanically handled) and then turned on a regular basis to ensure adequate aeration of the substrate, and that materials which has been on the outside of the pile may experience the pathogen –killing temperatures achieved within the piles. Turning could be done either manually or mechanically. To avoid nutrient losses through leaching and runoff, composting is better done on concrete floor with drainage system that enable collection of runoff in a concrete tank. The water collected is nutrient rich and can be used for irrigation.

Static aerated pile. This can be made either by inserting lengths of tubing such as bamboo into the pile so that air may penetrate, or by forced aeration using tubing and air pumps. No turning of the compost occurs within the static piles

In-vessel systems. In comparison to traditional windrow composting, in-vessel composting techniques often represent more effective waste management options due to the reduced production of bioaerosols and leachate and the potential for better process control. In-vessel composting provides the greatest control of the compositing environment resulting in the most rapid compost formation, but they are technologically complex and expensive and so are rarely suitable for large scale operations in developing countries.

Components of a composting plant may include magnets to remove metals hammer mill or shredders to reduce the size of materials before composting and sieve to remove inorganic, or large items that have not been humified during the composting process.

Small scale On-Farm Composting

Traditional on-farm composting is usually carried out in small scale. The methods however vary from place to place. Traditional methods include the heap method and the pit method and could be aerobic or anaerobic.

Example of anaerobic method is the *Indian Bengalore method*, a pit method used for composting night soil and refuse in region with scanty rainfall. *Passive composting of animal manure* naturally falls under the group of anaerobic method because the conditions for adequate aeration and optimum moisture is not met by just piling the refuse and leaving to decompose, as such anaerobic conditions normally develop within the pile.

The *Indian Indore method* is an example of aerobic decomposition through passive aeration. It could be carried out using the pit or heap method. In any case the principles of composting are maintained in the process. Pit method is better in less rainy condition. Otherwise, the pit would have to be sited on higher elevation or have a shed constructed to prevent rain. Heap method is more appropriate in raining season

Other methods include *the Chinese rural pit composting* method and *high temperature composts*. Rapid composting can be achieved by adhering to the principles of composting.
Some earthworms have the ability to improve organic waste by feeding on them and produce casts that are richer in nutrient content than the original waste. The system of compost production through this means is referred to as *vermicomposting*.

ORGANIC FARMING

Organic farming or organic agriculture is a farming system that makes use of techniques of soil care and cropping which are dependent on biological processes for sustainable food production through the use of local resources.

Organic farming differs from other farming systems in a number of ways. It favours renewable resources and recycling, returning to the soil the nutrients found in waste products. Where livestock is concerned, meat and poultry production is regulated with particular concern for animal welfare and by using natural foodstuffs. Organic farming respects the environment's own systems for controlling pests and disease in raising crops and livestock and avoids the use of synthetic pesticides, herbicides, chemical fertilisers, growth hormones, antibiotics or gene manipulation. Instead, organic farmers use a range of techniques that help sustain ecosystems and reduce pollution. It relies on developing biological diversity in the field to disrupt habitat for pest organisms, and the purposeful maintenance and replenishment of soil fertility.

In developed countries, there are standard organizations that monitor the quality of products. A product has to be verified by independent state or private organizations accredited by the government, and be certified. A certified organic refers to agricultural products that has bee grown ad processed according to uniform standards. Organic foods may not be more nutritious than the conventionally produced foods but they are definitely freer from pesticide residues (13% vs 71%).

BIOLOGICAL TRANSFORMATION OF NITROGEN

- Nitrogen exists in many forms and the transformations of N into these different forms are mostly mediated by microbes.
- Nitrogen in the atmosphere can be fixed into the soil industrially (fertilizer manufacture), through lightning and by microorganisms.

Biological N fixation (BNF)

- Describes the conversion of gaseous N_2 (dinitrogen gas) into organic forms mediated by microorganisms.

- BNF is a process exclusively restricted to the prokaryotes of the domain bacteria.

BNF is accomplished by

1. free-living N_2-fixing bacteria which asymbiotically fix N in the soil. Organisms such as *Azotobacter, Azospirillium, Beijerinckia* etc
2. Cyanobacteria such as *Anabaena azollae*, a microsymbiont of water fern Azolla/lichen
3. symbiotic N fixing association between legumes and rhizobia e.g *Rhizobium japonicum* and soyabean
4. symbiotic association between actinorhizal plants (non legumes) and Frankia (actinobacteria/actinomycetes). Actinorrhizal plants examples are Alnus casuarinas

  - BNF is catalysed by the *Nitrogenase* enzyme which is present in nitrogen-fixing organisms.
  - BNF is a reduction process and can be represented by the following equation

$$N_2 + 6H^+ + 6e- \rightarrow 2NH_3$$

Mineralization of N

- The conversion of organic N into inorganic forms, NH_4^+ (ammonium) is termed as mineralization of N.
- N mineralization involves two reactions which are **aminization** and **ammonification**.
- The NH_4^+ produced from ammonification is subject to several fates which include

1. conversion to NO_2^- and NO_3^- by the process of nitrification
2. absoption directly by plants
3. utilization by microorganisms (immobilization)
4. adsoption into clay lattice
5. Volatilization (slowly released back to the atmosphere as N_2).

- Mineralization of N involves diverse groups of aerobic and anaerobic bacteria, fungi and actinomycetes. Soil faunas also play important role in the mineralization process

Nitrification

This is the oxidation of NH3 or NH4+ to nitrite (NO2-) and nitrate (NO3-) mediated by bacteria that are called nitrifiers. Nitrification is used by several organisms as an energy source and it involves two steps. The first step is the conversion of NH4+ to NO2 which involves obligate autotrophic bacteria known as Nitrosomonas (Nitrosomonas communis, Nitrosomonas oligotropha).

$$2NH_4 + 3O_2 \xrightarrow[\textit{Nitrosomonas}]{} 2NO_2^- + 2H_2O + 4H^+$$

The second step is the conversion from NO2- to NO3- which involves another group of obligate autotrophic bacteria known as Nitrobacter.

$$2NO_2^- + O_2 \xrightarrow{\text{Nitrobacter}} 2NO_3^-$$

Immobilization

The incorporation of inorganic N into an organism is known as immobilization. It is the conversion of inorganic N (NH_4^+ or NO_3^-) to organic N and is basically the reverse of N mineralization. Immobilization can result in a decrease of simple plant available form of N in the soil. The extent of immobilization is controlled by C:N ratio. Immobilization is also carried out by arrays of aerobic and anaerobic bacteria, fungi and actinomycetes.

Denitrification

Denitrification is the reduction of soil nitrates to the N gases NO (nitric oxide), N_2O (nitrous oxide) and N_2. Most microorganisms that undertake denitrification (denitrifiers) do it when O_2 is otherwise unavailable such as in waterlogged condition. Few particular kind of facultative anaerobic organisms (but numerous in population) are responsible for denitrification and the active species belong to the genera *Pseudomonas, Bacillus* and *Clostridium*. Autotrophs such as *Thiobacillus denitrificans* and *T. thioparus* are also involved.

BIOLOGICAL TRANSFORMATION OF PHOSPHORUS

- Phosphorus (P) is the most limiting element for biological productivity apart from N.
- The P cycle is divided into two subcycles; the biological one and a geochemical cycle

P mineralization

Numerous soil microorganisms digest plant residues containing P and produce many organic P compounds in the soil. Organically bound P is not directly available to plants because it cannot be absorbed into cells in this form. Therefore, P must first be released from the organic molecules through mineralization. The final stage in the conversion of organically bound P to inorganic phosphate occurs through the action of phosphatase enzymes. These enzymes are produced by up to 70 – 80 % microbial populations which include bacteria like *Bacillus subtilis*, *Proteus* spp. and *Streptomyces* spp. and fungi such as *Aspergillus, Penicillium* and *Rhizopus* spp.

Immobilization of P

Soil microorganisms immobilize solution P and some P in plant residues as microbial P which later produce labile and stable organic P. The extent of P immobilization is affected by the C:P ratio of the organic materials being decomposed and the amount of available P in solution. Immobilization of P in soil by microorganisms may contribute to P deficiency of crop plants. P in soil may also be taken up by mycorrhizas and transferred to plants causing P to be immobilized in plants.

Solubilization of P

Some phosphate-solubilizing microorganisms have been identified. These organisms are capable of converting the insoluble rock phosphate into soluble form through the process of acidification, chelation, and exchange reactions. Examples of some of these organisms are *Aspergillus niger*, *Pseudomonads* spp.

Biological transformation of sulphur

Mineralization of sulphur

Mineralization of S is the conversion of organic S to inorganic SO_4^{2-}. Conversion processes of organic S to inorganic SO_4^{2-} involves many oxidation processes carried out by microorganisms and action of some enzymes. Mineralization occurs through various pathways which include direct aerobic mineralization during oxidation of C as energy source, anaerobic mineralization of organic matter, incomplete oxidation of organic S into inorganic compounds, biological oxidation of H_2S to sulphate via elemental S and sulphite.

Immobilization of sulphur

Immobilization of S is the conversion of inorganic S to organic S. It is a reduction process involving series of enzymatic reactions. It is usually referred to assimilatory sulphate reduction. Microbial decomposition of plant residues results in S immobilization when the C:S ratio is high (>400:1).

Oxidation

Sulphur oxidation is a reaction used by some particular group of microorganisms to obtain energy. One of such group is the genus of autotrophic bacteria. The oxidation of sulphur produces sulphate SO_4^{2-}. The reaction is

$$S \rightarrow SO_3^{2-} \rightarrow SO_4^{2-}$$

Many species of autotrophic microorganisms oxidize reduced S compounds to elemental S but the species of Thiobacillus such as *T. denitrificans*, *T thiooxidans* and *T. ferrooxidans* deserves special mention as it produces sulphuric acids when elemental S is added to soil reducing soil pH to as low as 2.0 after prolonged incubation with the bacteria. The H_2SO_4 produced helps in nutrient mobilization by increasing the level of phosphate thereby enhancing phosphorus nutrition of plants. Oxidation of sulphur occurs in extreme environments such as hot sulphur spring, saline lakes under anaerobic conditions by organisms such as *Chlorobium*.

Reduction

Reduction of oxidized form of S particularly SO_4^{2-}, by microorganisms occur in two different ways.

1 **Assimilatory sulphate reduction.** This process may also be referred to immobilization. Sulphur is incorporated into cellular constituents such as S in amino acids and protein biosynthesis by microorganisms and plants.

2. **Dissimilatory sulphate reduction**: This is a process in which reduction of sulphates leads to the formation of sulphides (e.g. H_2S) as the end product. The process is mediated by anaerobic organotrophic bacteria of the *Desulfovibrio* and *Desulfotomaculum* group.

Sulphate reduction is not important in well aerated soil but waterlogged soil. The sulphate-reducing bacteria are regulator of variety of processes in anaerobic upland and wetland soils including organic matter turnover, biodegradation of chlorinated aromatic pollutants etc.

Root nodule bacteria

Several genera of root nodule bacteria exist in rhizosphere. These include rhizobial group that nodulate legumes (*Allorhizobium, Azorhizobium, bradyrhizobium, Mesorhizobium, Sinorrhizobium* and *Rhizobium)* and *Frankia* that nodulate non-leguminous plants.

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 process of establishing the symbiotic relationship is highly specific. One *Rhizobium* strain can infect certain species of legumes but not others e.g. 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.

Nodulation process is regulated by highly complex chemical communications between the plant and the bacteria. Once bound to the root hair, the bacteria stimulate the hair to curl. Rhizobia then invade the root through the hair tip where they induce the formation of an infection thread. 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. Each root nodule is packed with thousands of living *Rhizobium* bacteria, most of which are in the misshapen form known as bacteroids. 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.

Mycorrhizal Relationship

Mycorrhiza is the mutualistic symbiosis between soil borne fungi and roots of higher plants. The word was coined by Frank (1985) 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 fungi are usually non pathogenic. 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; Ectomycorrhizae and 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 an 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 structure 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.
2. Improved tolerance to water stress

3. Disease tolerance in crop.
4. Improvement of soil structure.

Organic manures and wastes

Organic manures are materials largely of plant and animal origin in different states of decomposition that are added to soil to supply plant nutrients and improve soil physical properties. They are made from cattle dung, excreta of other animals, rural and urban composts, other animal wastes, crop residues, green manures and industrial organic wastes such as paper and sugar industries and sewage sludge. Organic manures are rich in water and C compounds but poorer in plant nutrients than inorganic manures.

Types of organic manures

1. **Farm yard manure**: This is the waste from mixed arable and livestock farming used to fertilize crops. It consists of animal excreta (cattle, goat and sheep dung and urine, poultry litters) mixed with bedding materials such as straw, wood chips, crop residues etc. Farm yard manure supplies both macro and micronutrients to plants.
2. **Crop residues**: These include plant parts that remain on land after crop harvest.
3. **Compost manure**: This is made by accelerating the rate of humification of plant and animal residues by microorganisms in well aerated condition.
4. **Green manure:** These are green plants used in fertilizing soil. Green manuring is the practice of ploughing in a quick-growing leafy crop before maturity. Leguminous plants are largely used as green manure due to their symbiotic N fixing capacity. Some non-leguminous plants may also used due to local availability, drought tolerance, quick growth and adaptation to adverse conditions e.g *Tithonia diversifolia*
5. **Slurry**: This is a suspension of dung in the urine and washing water coming from animal houses and milking parlours.
6. **Sewage sludge:** It is an end product of wastewater treatment process, consisting of solids separated from liquid raw sewage. Sewage sludges vary in condition from sticky materials containing half their weight of water to well dried powder, easy to handle and spread. Sludges are processed and transformed into biosolids using a number of complex treatments such as digestion, thickening, dewatering, drying, and lime/alkaline stabilisation. Digested sludges are fermented anaerobically to eliminate offensive odours and lower the count of pathogens and may safely be applied to the land. However, sustained heavy application of sludges may introduce pathogens into soil and/or raise heavy metals content such as Zn, Cu, Ni and Cd to levels that are detrimental to plants.

Benefits of organic manure to sustainable agriculture

1. It builds soil organic matter thus improving soil quality
2. It serves as nutrient reserves thus improving soil fertility
3. It improves soil physical properties like
4. It buffers against rapid changes in acidity, alkalinity and salinity of soil
5. It improves soil structure and reduces soil crusting
6. It provides energy substrate for microbial transformations.

Composition of manures

Organic manures vary in composition of their nutrients. Variability in elemental and composition among and within organic fertilizer types is due to factors such as differences in source (whether animal or plant origin), animal species or breed, population of animal, feed ration and conversion rate of animal, bedding material type and composition if present, climatic condition during manure accumulation, plant species or variety added as residues, age of plant material and environment of operation (industrial or domestic)

Soil Biotechnology

Soil biotechnology is the study and manipulation of soil microorganisms and their metabolic processes to optimize crop productivity. It involves the use of techniques of recombinant deoxyribonucleic acid (DNA) technology, gene transfer, embryo manipulation and transfer, plant regeneration, monoclonal antibodies and bioprocessing to generate unique organisms with new traits or organisms that have the potential to produce specific products. Soil biotechnology application in agriculture has played major role in

1. Improving the growth and yield of crops through application of bio-inoculants such as rhizobia, mycorrhiza and other plant growth promoting organisms.
2. Protecting crops against pests and diseases through the use of organisms such *Bacillus thuringiensis* (Bt) which is a microbial insecticide.
3. Remediating the soil of wide range of pollutants by using catabolic versatility of microorganisms to degrade or convert toxic compounds in the soil.

Biofertilization by Rhizobia inoculation

The introduction of rhizobium into soils through a carrier substance such as peat containing the organism onto the legume seed represents the earliest attempt at inoculation. Researchers are pursuing a no of different strategies to improve N fixation. They want to genetically engineer rhizobium to fix N more efficiently for their natural host legumes and to create rhizobium that could infect and fix N for other plants particularly cereals.

Biofertilization by Mycorrhizal inoculation

The root of most plant species in natural environment or in cultivation form symbiotic association, termed mycorrhiza, with specialised fungi. Inoculation of mycorrhizas is possible through the use of mycorrhizal inoculum which is usually a mixture of soil, plant root and mycorrhizal propagules (spores and hyphae or mycelium). Pure mycorrhizal inoculum contains only a species of mycorrhizal fungi while mixed inoculum contains two or more species of mycorrhizal fungi. Tree crops such as cocoa, citrus, apple and some forest trees are inoculated with mycorrhiza in the nursery to aid their vigour and establishment on the field. Annual crops like maize, wheat, yams and many horticultural crops are also inoculated during planting in pots and on the field. There are now commercial mycorrhizal inoculants being sold in many developed countries.

Genetically modified organisms (GMOs)

A genetically modified organism (GMO) is an organism whose genetic material has been altered using techniques generally known as recombinant DNA technology. The organism can be a plant or animal. GMOs are created when DNA molecules from different sources are combined into one molecule to create a new set of genes. This DNA is then transferred into an organism, giving it modified or novel genes. Transgenic organisms (GMOs which have inserted DNA that originated in a different species) and or cisgenic organisms (GMOs that contain no DNA from other species) are formed when genetic modification of organisms occurs.

There are environmental and health concerns about the use of GMOs especially modified microorganisms. It will soon be possible to engineer bacteria and viruses to produce deadly pathogens. This could open a new era in biological weapons in addition to the environmental problems that could result from the release of organisms into the environment. The environmental assessment of the widespread introduction of engineered microorganisms has only barely begun to receive attention.

Biodegradation of 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. 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 or hazardous to human beings as well as livestock's.

Process of biodegradation of pesticides in soil

The process of degradation of pesticides and conversion into non-toxic compounds by microorganisms is known as “biodegradation”. Not all pesticides reaching 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.

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 a process known as mineralization, 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. 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..

The chemical reactions leading to biodegradation of pesticides fall into several broad categories which include, detoxification, degradation**,** conjugation (complex formation or addition reaction), activation and **c**hanging the spectrum of toxicity.

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. The chemical structure of pesticides seriously affects its degradation..