Role of Microoraganisms in Organic Matter (Cellulose, Hemicellulose, Lignin) Decomposition

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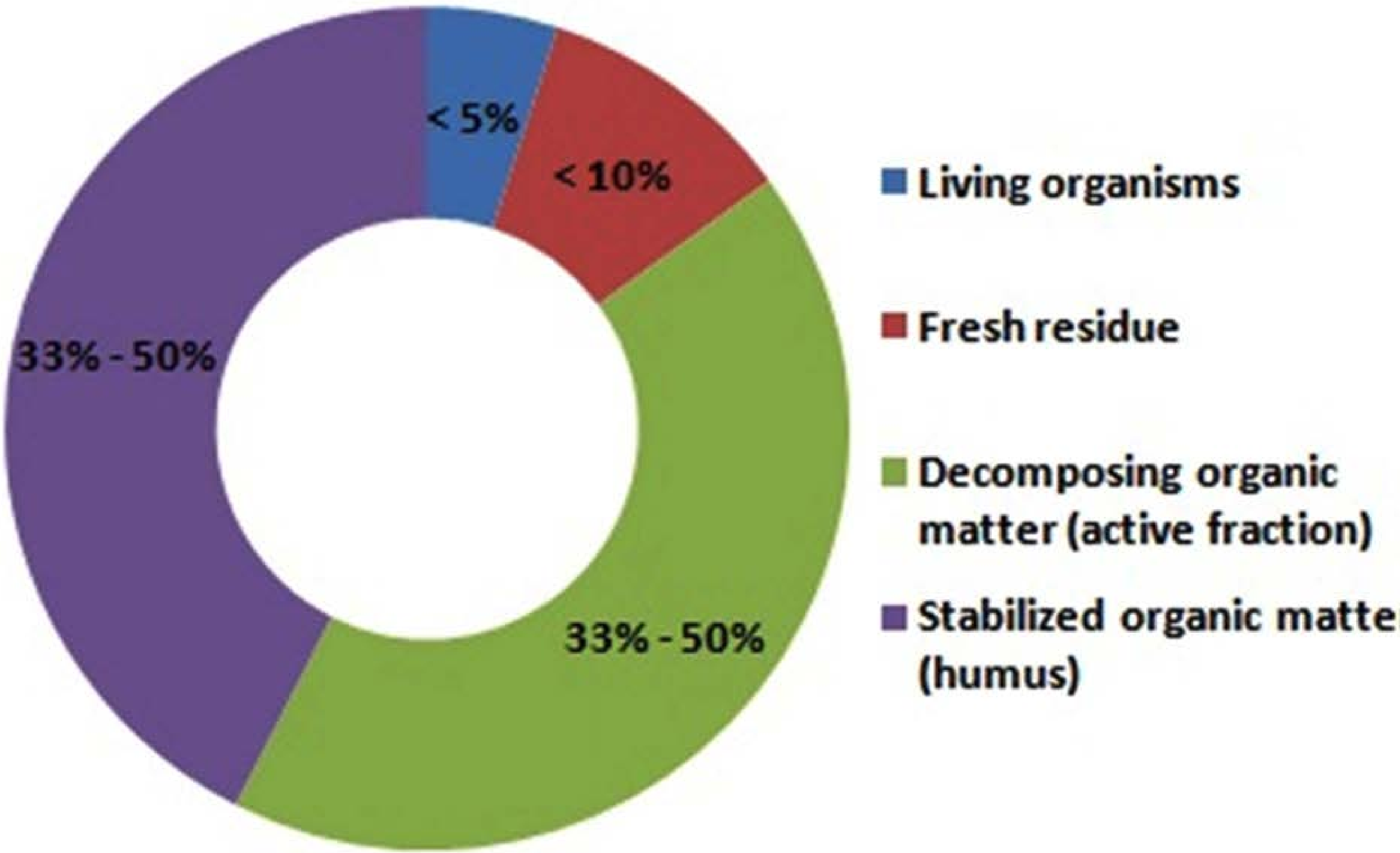
Introduction

- Organic matter is mainly present in the top 20–30 cm of most soil profiles and is essentially an array of organic macromolecules.
- Almost all organic matter in soil is directly and indirectly derived from plants via photosynthesis.
- The most important pathways by which the fixed carbon is retained and ultimately transferred to the soil ecosystem are the direct addition of senescent material as above-ground and below-ground detritus, return of ingested plant matter in animal faeces, and exudation of soluble organic compounds from roots.
- Plant and animal detritus and root exudates represent essential sources of energy and nutrients for soil microbial and faunal communities.
- Bacteria and fungi represent 95%+ of the biomass present in most soils, where they interact with a combination of micro-fauna (nematodes, protozoa), meso-fauna (acari, Collembola, mites) and macro-fauna (earthworms, termites, molluscs) in complex soil food-web systems that determine the turnover of organic matter and associated nutrients in the soil environment.
- Decomposition depends on multiple factors that are being altered simultaneously as a result of global environmental change.

Major soil organic matter components



Decomposition Process

- Decomposition is the breakdown, by physical and biological mechanisms, of organic substances found in the soil.
- Plant remains, deposited on or in the soil, are known as plant litter.
- Concomitant with the breakdown of litter is the synthesis of meta-stable substances known as humus.
- During decomposition inorganic substances including plant nutrients are both released (mineralized) from and incorporated (immobilized) into the decaying material.
- Animal remains are qualitatively quite different from plant remains.
- Most of the decay process is biologically mediated. In soils, bacteria and fungi are the major microbial agents of decay.

… Decomposition Process

- Fungi and bacteria function similarly with regard to decomposition.
- Organic matter decomposition serves three functions for the micro flora: (i) providing energy for growth,

  (ii) supplying carbon for the formation of cell material, and

  (iii) providing other nutrient, elements needed for cell growth.
- Soluble substances such as sugars and low molecular weight phenolic compounds are assimilated by the microorganisms and metabolized.
- However, a large fraction of plant litter is composed of high-molecular weight polymers such as celluloses, lignin and suberin, which cannot be directly assimilated by microorganisms.
- Rather, extracellular enzymes must first break them down.
- Organic residues added to the soil are first broken down into their basic components by extracellular enzymes; and the basic components are subsequently utilized by intracellular enzymes.

… Decomposition Process

- The process of decomposition is initially fast, but slows down considerably as the supply of readily decomposable organic matter gets exhausted.
- Sugars, water-soluble nitrogenous compounds, amino acids, lipids, starches and some of the hemicelluloses‘ are decomposed first at rapid rate, while insoluble compounds such as cellulose, hemicelluloses, lignin, proteins etc. which forms the major portion of organic matter are decomposed later slowly.
- Thus, the organic matter added to the soil is converted by oxidative decomposition to simpler substances which are made available in stages for plant growth and the residue is transformed into humus.

Plant Cell Wall

- The cell wall of a higher plant is made up of about 90% carbohydrates and 10% proteins.
- The main carbohydrate constituent is **cellulose.**
- About 36 cellulose chains are associated by interchain hydrogen bonds to a crystalline lattice structure known as a **microfibril.**
- The microfibrils have an unusually high tensile strength, are very resistant to chemical and biological degradations.
- However, many bacteria and fungi have cellulose-hydrolyzing enzymes.
- Hemicelluloses are also important constituents of the cell wall.
- Hemicelluloses consist of a variety of polysaccharides that contain, in addition to D-glucose, other carbohydrates such as the hexoses D-mannose, D-galactose, D-fucose, and the pentoses D-xylose and L-arabinose.
- Another major constituent is pectin, a mixture of polymers from sugar acids, such as D-galacturonic acid, which are connected by β-1,4 glycosidic links.
- Pectin makes the wall elastic and, together with the glycoproteins and the hemicellulose, forms the matrix in which the cellulose microfibrils are embedded.

… **Plant Cell Wall**

- When the cell has reached its final size and shape, another layer, the secondary wall, which consists mainly of cellulose, is added to the primary wall.
- The microfibrils in the sec. wall are arranged in a layered structure like plywood.
- The incorporation of lignin in the secondary wall causes the lignification of plant parts and the corresponding cells die, leaving the dead cells with only a supporting function (e.g., forming the branches and twigs of trees or the stems of herbaceous plants).
- Lignin is formed by the polymerization of the phenylpropane derivatives cumaryl alcohol, coniferyl alcohol, and sinapyl alcohol, resulting in a very solid structure.

Cellulose decomposition

- When cellulose is associated with pentosans (eg. xylans & mannans) it undergoes rapid decomposition, but when associated with lignin, the rate of decomposition is very slow.
- The decomposition of cellulose occurs in two stages:

  (i) in the first stage the long chain of cellulase is broken down into cellobiase and then into glucose by the process of hydrolysis in the presence of enzymes cellulase and cellobiase, and

  (ii) in second stage glucose is oxidized and converted CO_2 and water.
- In order to access this glucose for catabolism, the cellulose must be decomposed by extracellular enzymes.
- Cellulases have different specificities to hydrolyse the β-1,4-glycosidic linkages bonds that connect glucose units in the cellulose fiber.
- They are divided into three major classes:
  - endoglucanases (endo-1-4-β-glucanase) : internally cleave β-1,4-glycosidic bonds in the amorphous regions of cellulose thereby releasing reducing and nonreducing chain ends.

… **Cellulose decomposition**

- Exoglucanases : remove dimers (cellobiose) from the end of the cellulose chain.
- β-glucosidase : hydrolyse glucose dimers and in some cases gluco-oligosaccharides to glucose.

- These pieces are then transported into the cell for energy generation (catabolism) or production of biomass (anabolism).
- Fungi such as *Penicillium* and *Aspergillus,* and bacteria such as *Streptomyces* and *Pseudomonas* are important participants in the extracellular cleavage of cellulose.
- The most extensively studied sources of cellulolytic enzymes have been the fungi *Trichoderma* and *Phanerochaete* and the bacteria *Cellulomonas* (an aerobe) and *Clostridium thermocellum* (an anaerobe).

Hemicellulose decomposition

- Hemicelluloses are water-soluble polysaccharides and consist of hexoses, pentose, and uronic acids and are the major plant constituents second only in quantity of cellulose, and sources of energy and nutrients for soil micro flora.
- The hydrolysis is brought about by number of hemicellulolytic enzymes known as "hemicellulases" excreted by the microorganisms.
- On hydrolysis hemicelluloses are converted into soluble monosaccharide/sugars (e.g. xylose, arabinose, galactose and mannose) which are further convened to organic acids, alcohols, CO_2 and H_2O and uronic acids are broken down to pentose and CO_2.
- Various microorganisms including fungi, bacteria and actinomycetes both aerobic and anaerobic are involved in the decomposition of hemicelluloses.

… **Hemicellulose decomposition**

- Hemicellulose hydrolysis demands cooperative action of several types of enzymes working at different levels of the hemicelluloytic matrix.
- This synergistic activity is necessary not only because of hemicellulose complexity but also because of its connection with the other plant cell wall components.
- According to their action on distinct substrates two types of enzymes are predominantly involved in hemicellulose degradation:
  - endo-1,4-β-xylanase : hydrolyse β-1,4-xylan chains, and generate xylo-oligosaccharides
  - exo-1,4-β-xylosidase : cleave xylobiose and xylo-oligosaccharides releasing xylose
- Mannan, as the major component of hemicellulose in softwood, is comprised of mannose residues or a combination of mannose and glucose residues also known as glucomannan.

... **Hemicellulose decomposition**

- β-Mannanases are endohydrolases that hydrolyse mannan fibers by cleaving β-1,4 bonds and producing new reducing and nonreducing ends.
- The hydrolytic action of β-mannanases on mannan is supported with β-mannosidase enzymes that carry out hydrolysis of terminal, nonreducing β-D-mannose residues.
- In case of glucomannan degradation, β-glucosidases can cleave the bond between one mannose and one glucose residue.
- One should be aware that the action of these enzymes strongly depends on the number and pattern formed by the substituted galactoses and other substitutions and on the action of other enzymes