



Biochemistry of Organic Matter Decomposition in Soil

*Poojitha K¹, Anil Kumar², Ravi Patel² and Manjul Jain²

¹Agronomist, Tene Agricultural Solutions Pvt Ltd., Bengaluru- 560064

²Assistant Professor, Department of Agronomy, School of Agriculture,

Eklavya University Damoh, Madhya Pradesh-470661

*Corresponding Author's email: poojitha054@gmail.com

Soil organic matter (SOM) decomposition is a fundamental biochemical process that regulates nutrient cycling, soil fertility, and ecosystem productivity. It involves the breakdown of plant and animal residues by soil microorganisms through complex enzymatic reactions. The decomposition process releases essential nutrients such as nitrogen, phosphorus, and sulfur, making them available for plant uptake. This article discusses the biochemical mechanisms, stages, controlling factors, and significance of organic matter decomposition in soil systems.

Introduction

Soil organic matter (SOM) is a complex mixture of plant residues, animal remains, microbial biomass, and humus present in the soil. It plays a vital role in maintaining soil health by improving soil structure, enhancing water holding capacity and increasing nutrient availability for plants. The decomposition of organic matter is a biologically driven process carried out by soil microorganisms such as bacteria, fungi, and actinomycetes. These microorganisms break down complex organic compounds into simpler forms through enzymatic reactions, releasing essential nutrients into the soil. This process is fundamental for sustaining soil productivity and ecosystem balance. Decomposition is essential for recycling nutrients, maintaining soil fertility, supporting plant growth, and regulating the global carbon cycle, thereby contributing to sustainable agricultural systems and environmental stability.

Composition of Soil Organic Matter

Soil organic matter (SOM) is a complex and dynamic mixture of organic compounds derived from plant residues, animal remains, and microbial biomass. It consists of substances at different stages of decomposition, ranging from fresh residues to highly stable humus. The composition of SOM plays a vital role in determining soil fertility, structure, and biological activity.

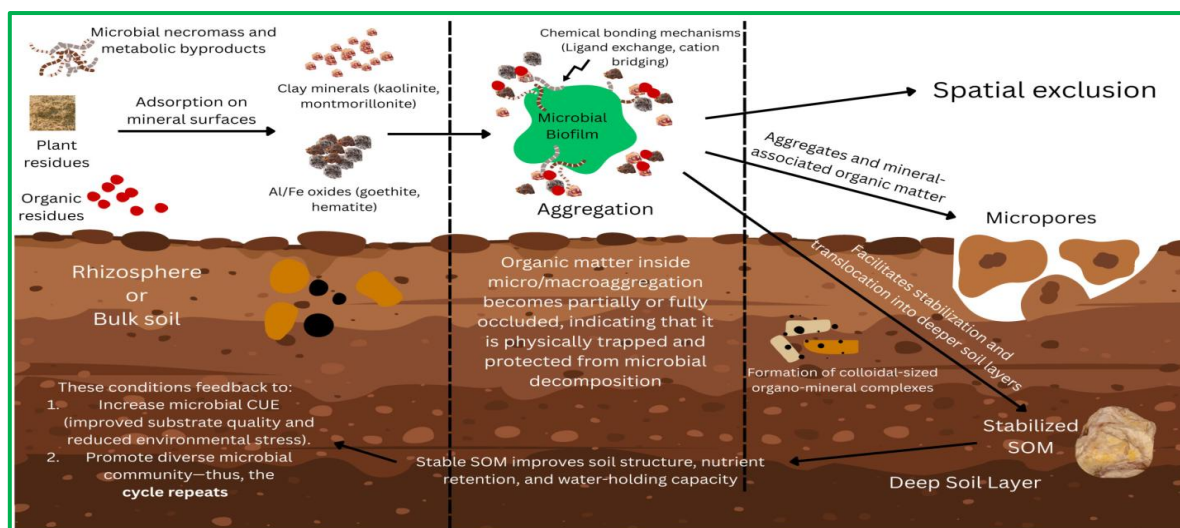
Carbohydrates are one of the major components of SOM and include cellulose, hemicellulose, and simple sugars. These compounds are readily decomposed by soil microorganisms and serve as an important energy source, supporting rapid microbial growth and activity.

Proteins are organic compounds made up of amino acids and are a key source of nitrogen in soil. During decomposition, proteins are broken down into ammonium and other nitrogenous compounds, which are essential for plant nutrition.

Lipids, including fats, waxes, and oils, are relatively resistant to decomposition due to their hydrophobic nature. They contribute to the long-term organic matter pool and help improve soil aggregation.

Lignin is a complex aromatic polymer present in plant cell walls. It is highly resistant to microbial attack and decomposes slowly, mainly through the action of fungi, contributing to the formation of stable organic matter.

Humus is the most stable and well-decomposed fraction of SOM. It is dark in color, resistant to further breakdown, and plays a crucial role in improving soil structure, water retention, and nutrient holding capacity.



Source: <https://www.mdpi.com/>

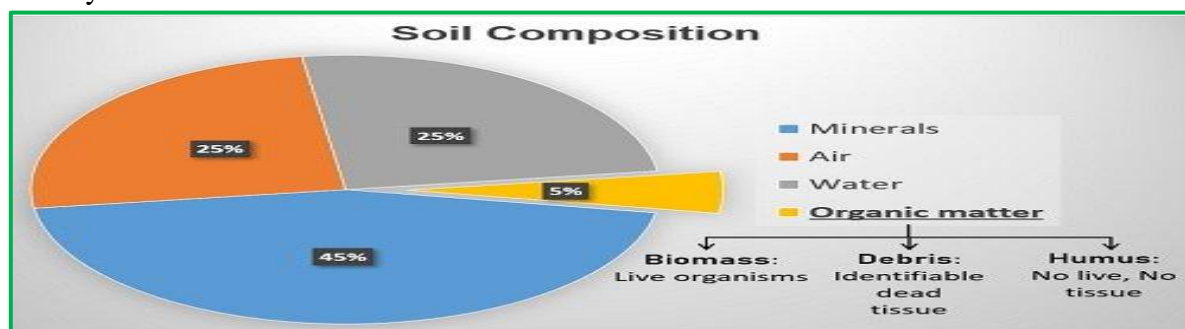
Microorganisms Involved in Decomposition

The decomposition of soil organic matter is a biologically driven process carried out by a diverse group of soil microorganisms. These microorganisms play a crucial role in breaking down complex organic materials into simpler compounds, thereby releasing essential nutrients into the soil. The major groups involved in decomposition include bacteria, fungi, and actinomycetes, each having specific functions in the process.

Bacteria are the most abundant microorganisms in soil and are primarily responsible for the decomposition of simple and easily degradable organic compounds such as sugars, amino acids, and proteins. They are highly active during the initial stages of decomposition when fresh organic matter is available. Bacteria multiply rapidly under favorable conditions of moisture, temperature, and aeration, contributing significantly to nutrient mineralization.

Fungi are important decomposers of complex organic substances such as cellulose, hemicellulose, and lignin. They possess specialized enzymes that enable them to break down these resistant compounds. Fungi dominate in acidic soils and under conditions where organic residues are more complex. Their hyphal network also helps in binding soil particles, improving soil structure.

Actinomycetes are filamentous microorganisms that share characteristics of both bacteria and fungi. They are particularly effective in decomposing resistant materials such as lignin, chitin, and cellulose during the later stages of decomposition. Actinomycetes also produce a characteristic earthy smell in soil and contribute to humus formation, thereby enhancing soil fertility.



Source: <https://biologyreader.com/>

Biochemical Processes of Decomposition

The decomposition of soil organic matter involves several complex biochemical processes carried out by soil microorganisms. These processes convert organic compounds into simpler substances and ultimately release nutrients in forms available to plants. The major biochemical processes include enzymatic breakdown, mineralization, immobilization, and humification.

Enzymatic Breakdown:

Microorganisms secrete extracellular enzymes that degrade complex organic molecules into simpler compounds. For example, cellulase breaks down cellulose into simple sugars, protease converts proteins into amino acids, lipase decomposes fats into fatty acids and glycerol, and ligninase helps in the breakdown of lignin. This step is essential for initiating the decomposition process and making nutrients accessible for further transformations.

Mineralization:

Mineralization is the process by which organic nutrients are converted into inorganic forms that plants can absorb. During ammonification, organic nitrogen is converted into ammonium (NH_4^+). This is followed by nitrification, where ammonium is oxidized into nitrate (NO_3^-). Similarly, organic phosphorus is converted into inorganic phosphate, making it available for plant uptake.

Immobilization:

Immobilization is the temporary uptake and assimilation of nutrients by microorganisms for their growth. During this process, nutrients such as nitrogen become unavailable to plants for a short period, especially when organic matter has a high carbon-to-nitrogen ratio.

Humification:

Humification involves the transformation of partially decomposed organic matter into stable humus. This process enhances soil fertility, structure, and long-term nutrient retention.

Stages of Organic Matter Decomposition

The decomposition of organic matter in soil occurs in a series of stages, each characterized by specific biochemical activities and microbial dominance. These stages reflect the gradual transformation of complex organic materials into stable humus.

Initial Stage:

The initial stage begins immediately after the addition of fresh organic residues such as crop residues or animal wastes. In this phase, easily soluble compounds like sugars, amino acids, and simple proteins are rapidly decomposed by bacteria and other microorganisms. Microbial activity is very high due to the availability of readily accessible energy sources. This stage is short but crucial, as it initiates the decomposition process and releases some nutrients quickly.

Active Stage:

In the active stage, microorganisms start decomposing more complex compounds such as cellulose, hemicellulose, and proteins. Fungi and actinomycetes play a significant role during this phase. Nutrient release becomes more pronounced, especially nitrogen, phosphorus, and sulfur. The rate of decomposition is moderate, and microbial population remains high. This stage contributes significantly to soil fertility through nutrient mineralization.

Final Stage:

The final stage involves the decomposition of highly resistant compounds such as lignin and complex organic residues. This process is slow and leads to the formation of stable humus. Microbial activity decreases, and only specialized organisms are involved. The humus formed improves soil structure, water holding capacity, and long-term nutrient availability, making it essential for sustainable soil health.

Factors Affecting Decomposition

The rate and efficiency of organic matter decomposition in soil are influenced by several environmental and biological factors. These factors regulate microbial activity and determine how quickly organic residues are broken down.

Temperature:

Temperature is one of the most important factors affecting decomposition. The optimum range for microbial activity is 25–35°C. Within this range, enzymatic reactions occur rapidly, leading to faster breakdown of organic matter. Extremely high or low temperatures reduce microbial activity and slow decomposition.

Moisture:

Adequate soil moisture is essential for microbial growth and enzyme function. Moist conditions facilitate the movement of nutrients and microorganisms. However, excessive moisture leading to waterlogging creates anaerobic conditions, while very dry soil limits microbial activity, both resulting in slower decomposition.

Aeration:

Oxygen availability is crucial for aerobic microorganisms, which are more efficient in decomposing organic matter. Well-aerated soils promote rapid decomposition, whereas anaerobic conditions (lack of oxygen) slow down the process and may produce undesirable by-products like methane and organic acids.

Soil pH:

Soil pH significantly affects microbial populations and enzyme activity. Neutral pH conditions (around 6.5–7.5) are most favorable for decomposition. Extremely acidic or alkaline soils reduce microbial efficiency and slow down the breakdown process.

C:N Ratio:

The carbon to nitrogen (C:N) ratio of organic material is a key factor. An ideal ratio of 20:1 to 30:1 promotes balanced microbial activity. A high C:N ratio slows decomposition due to nitrogen limitation, while a low ratio accelerates it.

Role of Decomposition in Soil Fertility

Decomposition of organic matter plays a vital role in maintaining and improving soil fertility. During this process, complex organic compounds are broken down into simpler inorganic forms, leading to the release of essential plant nutrients such as nitrogen (N), phosphorus (P), and potassium (K). These nutrients become available for plant uptake, thereby supporting healthy crop growth and development.

In addition to nutrient release, decomposition improves **soil structure** by promoting the formation of stable aggregates. This enhances soil aeration, root penetration, and resistance to erosion. The formation of humus during decomposition further increases the **water holding capacity** of soil, helping crops withstand drought conditions.

Decomposition also stimulates **microbial activity**, as microorganisms depend on organic matter as a source of energy and nutrients. A biologically active soil supports various beneficial processes, including nutrient cycling and disease suppression.

Carbon Cycle and Decomposition

Decomposition is a crucial component of the global carbon cycle. During the breakdown of organic matter, soil microorganisms convert organic carbon into carbon dioxide (CO₂), which is released into the atmosphere through respiration. This process links soil systems with atmospheric carbon dynamics. At the same time, a portion of the decomposed organic matter is transformed into stable humus, which acts as a long-term carbon reservoir in the soil. This stored carbon improves soil fertility and contributes to carbon sequestration. Thus, decomposition plays a dual role by both releasing carbon into the atmosphere and storing it in soil. Proper management of organic matter can help regulate atmospheric CO₂ levels, thereby contributing to climate change mitigation and environmental sustainability.

Importance in Sustainable Agriculture

The decomposition of organic matter is a cornerstone of sustainable agriculture, as it ensures long-term soil productivity and environmental health. One of its primary benefits is the maintenance of **soil health**, as decomposed organic matter improves soil structure, enhances

aeration, and increases water holding capacity. This creates a favorable environment for root growth and microbial activity.

Decomposition also **reduces dependence on chemical fertilizers** by naturally supplying essential nutrients such as nitrogen, phosphorus, and potassium through mineralization. This not only lowers input costs for farmers but also minimizes environmental pollution caused by excessive fertilizer use.

Organic farming systems where natural nutrient cycling is essential for crop production. The continuous addition and decomposition of organic residues help maintain soil fertility without synthetic inputs.

Enhancement of crop productivity Soils rich in organic matter provide balanced nutrition, better moisture retention, and improved biological activity, leading to healthier crops and higher yields.

Conclusion

The biochemistry of organic matter decomposition is a vital process in soil ecosystems that involves microorganisms, enzymes, and environmental factors. It converts organic residues into simpler compounds and stable humus, ensuring continuous nutrient recycling and maintaining soil fertility. Understanding this process helps improve soil management practices such as residue management, balanced fertilization, and moisture control. Efficient decomposition enhances nutrient availability, supports plant growth, and promotes soil health. In sustainable agriculture, it reduces dependence on chemical fertilizers and contributes to environmental conservation, making it essential for long-term agricultural productivity and ecological stability.

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