Restoration of Agriculture Ecosystem, Soil Nutrients and Carbon Dynamics

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Edited by

Imran and Ibrahim Ortas

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Dr. Imran's research interests include crop nutrition, crop physiology, degraded soil management, nutrient budgeting, crop competition, weed and crop management, and sustainable agriculture under stressful environments. Additionally, he possesses expertise in climate forecasting, climate corridors, and agro-meteorology.

Professor Ibrahim Ortaş is a dedicated full-time faculty member at Çukurova University, serving at the Faculty of Agriculture in the Department of Soil Science and Plant Nutrition, located in Adana, Turkey. He earned his Ph.D. from the University of Reading, UK, and currently conducts impactful research and imparts knowledge at Çukurova University.

Prof. Ortaş oversees the Rhizosphere Laboratory, playing a pivotal role in both research and practical applications. His extensive research encompasses various areas:

1. Soil science and plant nutrition, with a focus on the impact of mycorrhizae on mineral nutrient uptake, particularly in phosphorus (P) and zinc (Zn) absorption.
2. Application of mycorrhiza in sustainable agricultural systems.

3. Production of mycorrhizae-inoculated seedlings under micro-propagated conditions.
4. Long-term field experiments, including the effects of organic manure, compost, mycorrhizal inoculum, and inorganic fertilizer on pepper growth and nutrient uptake, as well as the long-term impact of phosphorus (P) fertilization on soil quality.
5. Agricultural management and soil protection.
6. Mycorrhizae and belowground carbon sequestration in forestry ecosystems.
7. Climate change and food sequestration.
8. Biochar and mycorrhiza contributions to the soil organic carbon pool and atmospheric carbon mitigation.

His recent work delves into belowground carbon pools, focusing on soil organic carbon and nitrogen mineralization related to CO_2 flux under long-term field conditions. Currently, he is investigating the influence of vouchers on the carbon budget of citrus tree plants and soil carbon sequestration.

Prof. Ortaş has a global perspective, having visited over 43 countries for joint scientific meetings, conferences, and talks at various scientific congresses. He has successfully completed numerous research projects, including 7 COST actions, 3 EU-projects, 3 State Planning Organizations projects, 29 projects funded by The Scientific and Technological Research Council of Turkey (TÜBİTAK), and 54 national projects.

In the academic realm, Professor Ortaş imparts knowledge in courses such as Soil Science, Plant Nutrition, The Rhizosphere's Ecology, The Impacts of Mycorrhizae on Nutrient Uptake, and The Interaction Between Soil, Crop, and Atmosphere regarding Climate Change and Soil-Crop Management. Additionally, he teaches Soil History and Agriculture, as well as Academic Ethics and Scientific Methods. He holds the responsibility for the Agriculture Research Farm of the Department of Soil Science and Plant Nutrition.

Prof. Ortaş is a prolific author, with 94 SCI full articles, two books, and 28 book chapters to his credit. He has published over 598 articles and organized six international meetings and workshops. His scholarly contributions have garnered 1613 citations, with an H-index of 22. Outside the academic arena, Prof. Dr. Ortaş is also a skilled free-hand writer, having written over 1200 articles on education, the philosophy of science, the environment, and sustainable living, particularly focusing on the interconnectedness of humans, nature, and education. He frequently shares his thoughts and insights in various meetings and discussions within these domains.

SOIL CARBON DYNAMICS AND ITS RESTORATION FOR POTENTIAL YIELD

IMRAN, ABID KAMAL, ASAD ALI KHAN,
IBRAHIM ORTAS AND HAYAT ZADA

Abstract

Restoring soil carbon is a crucial process that involves sustainable land management practices, minimizing disturbances, and promoting organic matter input. It contributes to potential yield increases and ensures the long-term resilience and health of agricultural ecosystems. Farmers, researchers, and policymakers play vital roles in promoting and implementing these practices to address soil carbon dynamics. Soil organic carbon is a crucial element in Earth's ecosystems, influencing nutrient cycling, soil fertility, soil and water quality, biodiversity, crop productivity, climate change mitigation, resilience to climate change, and erosion control. Soil carbon plays a significant role in water retention, influencing the availability of water for plants and the overall health of ecosystems. Sustainable land management practices prioritize the conservation and enhancement of soil carbon, which acts as an energy source for microorganisms and a key component of organic matter, facilitating the release and availability of essential nutrients for plant growth. Soil fertility is essential for sustainable agriculture and ecosystem health, and farmers and land managers often conduct soil tests to assess nutrient levels and make informed decisions about fertilization practices. The effectiveness of soil carbon restoration and sustainable land management strategies may vary depending on factors such as climate, soil type and land use practices. Regular soil testing, computer-based statistical models, field-based measurements, and monitoring networks are valuable tools for farmers, land managers, and researchers to gather essential information about soil properties, including carbon levels. Successful soil carbon restoration requires a multidimensional approach that addresses soil health complexity, promotes sustainable and resilient agricultural systems, and encourages environmentally friendly practices. This multidimensional approach requires continued research, innovative practices, knowledge sharing, and supportive policies. Policy support is also

crucial for promoting environmentally friendly practices in the agricultural sector.

Keywords: Soil carbon dynamics and sequestration, Soil restoration, Agricultural yield, Carbon cycling, Soil health, Carbon storage, Sustainable agriculture Potential yield, Restoration strategies

Introduction

Soil carbon dynamics are crucial for understanding soil functions and predicting responses to changes in land use, climate, and management practices, as they control the development and maintenance of soil systems. These dynamics significantly influence the overall health and fertility of agricultural systems, affecting soil fertility, water retention, and ecosystem health (Imran, 2024a; Imran & Ortas, 2024). Effective soil carbon restoration involves the removal of CO_2 from the atmosphere through plant photosynthesis, the transfer of CO_2 from the atmosphere to plant biomass, and the subsequent transfer of organic carbon from plant biomass to the soil, forming a labile pool with a high turnover rate (Kuzyakov et al., 2019). Recent studies highlight the role of beneficial microbes in enhancing soil carbon sequestration and mitigating heavy metal contamination, thereby improving soil quality for forage crops (Imran et al., 2024; Quanheng Li & Imran, 2024). Furthermore, integrating organic and inorganic fertilizers can enhance nutrient cycling and soil health, promoting sustainable agricultural practices in changing climates (Imran, 2024b; Daguo Huang & Imran, 2023). Soil carbon projects involve removing carbon from the atmosphere and storing it in soil by increasing decomposing plant material and microbes. Carbon is a fundamental component of organic matter in the soil, and its concentration influences soil structure, nutrient availability, water retention, and microbial activity. Managing and restoring soil carbon is essential for sustainable agriculture and maximizing potential crop yields (Xu et al., 2020). Soil restoration is a method to improve compacted soils' porosity and nutrient retention by incorporating biological and mechanical methods such as aeration, tilling, planting dense vegetation, and applying soil amendments (Fig 1). Earth's soils contain approximately 2,500 gigatons of carbon (Lal, 2004), which is three times the amount in the atmosphere and four times the amount in all living plants and animals. The total carbon potential in terrestrial ecosystems is approximately 3170 gigatons, with nearly 80% found in soil. Soil carbon can be organic (1550 GT) or inorganic (950 GT), and can be found in either 1550 GT or 950 GT. Soil organic matter (SOM) is the primary way carbon is stored in the soil, consisting of decomposing plant and animal tissue, microbes, and soil minerals (Thakur et al., 2023). SOM is concentrated in topsoil, with some soils having less than 0.5% carbon, while others, like wetlands or peat forests, may have 10% or more. Soil-based carbon sequestration is crucial for preserving soil health and biodiversity (Ramesh et al., 2019).

Soil carbon dynamics play a pivotal role in enhancing soil health and fertility, which are critical for achieving potential crop yields. The restoration of soil carbon involves practices that promote carbon sequestration through plant growth and microbial activity, significantly impacting agricultural productivity (Imran, 2024a). Recent advancements in nanobiotechnology have shown promise in improving crop resilience against abiotic stresses, further supporting carbon dynamics in soil systems (Imran & Ortas, 2024). Utilizing beneficial microbes for heavy metal remediation not only helps in detoxifying contaminated soils but also enhances soil carbon content, thereby improving overall soil quality (Imran et al., 2024). Biochar applications have been effective in mitigating toxicities, such as cadmium, while enhancing the soil's capacity to retain carbon and nutrients (Huang & Imran, 2024). Integrating organic and inorganic fertilizers has been shown to improve nutrient cycling and, consequently, soil carbon dynamics, promoting higher yields in cropping systems like maize-wheat (Imran, 2024b). Strategies aimed at mitigating heavy metal toxicity also contribute to restoring soil carbon levels, benefiting both plant health and soil fertility (Li & Imran, 2024). Additionally, the use of nano-black carbon has improved phosphorus uptake and sustained soil health, underscoring its role in carbon dynamics (Huang & Imran, 2023). Research on mycorrhizal interactions emphasizes their potential to enhance plant nutrition and soil carbon retention, further bolstering food security (Yang et al., 2023). Overall, effective management of soil carbon dynamics is essential for maximizing agricultural productivity and ensuring sustainable farming practices (Imran, 2022b; Ilyas et al., 2020). The varied responses of crops like wheat to irrigation and nano-black carbon highlight the need for tailored approaches to optimize soil carbon restoration strategies (Imran, 2021b).

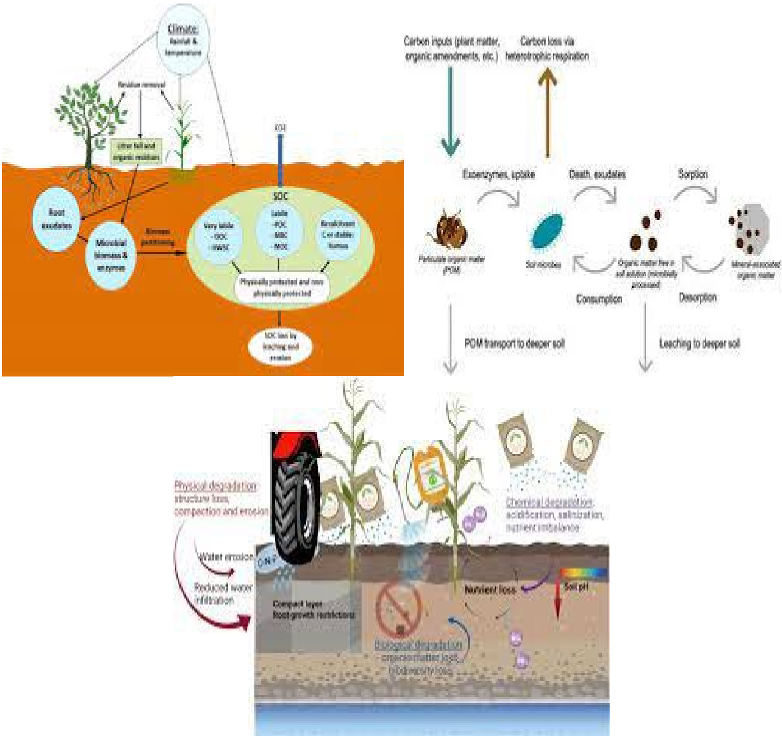

Figure 1. Biological, Chemical and mechanical ways of effecting soil and soil carbon

The scientific community is exploring the potential of enhancing soil carbon storage capacity to control emissions from terrestrial ecosystems. Restoration of damaged lands through conservation tillage, crop rotation, cover cropping, mulching, reforestation, sub-soiling, sustainable water management practices, and organic manuring are major antidotes against the attenuation of soil organic carbon (SOC) stocks (Bhattacharya et al., 2016). This research focuses on the effect of man-made activities on soil biotic organics, such as green-manure, farm-yard manure, and composts, to understand how C fluxes contribute to establishing a new equilibrium in terrestrial ecosystems. Although these inputs substitute some chemical fertilizers, they all undergo activities that increase the rate and extent of decay, depleting the SOC bank. Balancing factors control the mineralization rate of organic matter, considering different land use types and their impacts on forests, agriculture, urbanization, soil erosion and wetland destruction. Soil organic carbon is crucial for maintaining soil quality, and fertility and its impact on carbon and nitrogen dynamics is still being studied. Tillage and zero tilled soil significantly affect soil organic carbon build up and degradation. Organic manure treatments have higher SOC concentrations and stocks than mineral or unfertilized treatments (Lingutla Sirisha et al., 2019). Fertilization strategies incorporating organic manure can increase stable C in the surface soil layer and improve soil fertility.

1. Soil Carbon Dynamics

Soil carbon dynamics are crucial for understanding the development and maintenance of soil functions and predicting soil systems' responses to changes in land-use, climate, and management practices. Dynamic Carbon is a leading provider of carbon sequestering solutions that can help companies move towards net-zero emissions and save money through tax incentives (Khalifa et al., 2022). Soil carbon projects involve removing carbon from the atmosphere and storing it in soil by increasing decomposing plant material and microbes. Carbon in soil can be measured using wet digestion or dry combustion methods, with wet digestion oxidizing carbon using chemicals, and dry combustion generating carbon dioxide through thermal decomposition (Ramamoorthi and Meena, 2018). Organic carbon includes decaying plant matter, soil organisms, and carbon compounds like sugars, starches, proteins, carbohydrates, lignin's, waxes, resins, and organic acids. Inorganic carbon is mineral-based, with calcium carbonate being the most common form. Carbon and free carbon are different, with carbon-free states relying on clean energy sources like wind, solar, and nuclear, and free carbon companies intentionally removing more carbon than they produce (Gomes da Silva et al., 2020). Soil carbon pool is important for its role in the carbon cycle, as higher soil organic carbon promotes soil structure, improves aeration, water drainage, and reduces erosion and nutrient leaching (Fig 2).

1.1 Organic Matter Decomposition

Organic matter decomposition is a natural process in which complex organic compounds, derived from living organisms, are broken down into simpler substances by the action of microorganisms. This process plays a crucial role in nutrient cycling and the maintenance of ecosystem health. Decomposition of organic matter is a process that involves the physical breakdown and biochemical transformation of complex organic molecules into simpler organic and inorganic molecules (Nivethadevi et al., 2021a). The

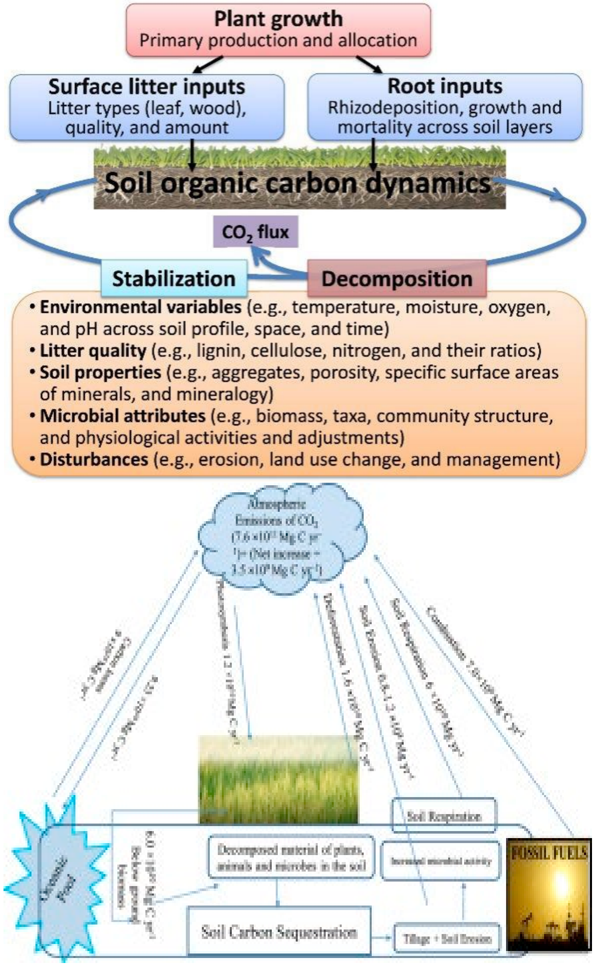

Figure 2. Carbon cycle influencing plant growth and soil carbon dynamics

process occurs in three phases: aerobic, transient, and anaerobic. The initial decomposition occurs under aerobic conditions, where putrefying bacteria use amino acids or urea as energy to decompose dead organisms, producing ammonium ions and releasing ammonia (Fig 3). The process involves five steps: fragmentation, leaching, catabolism, humification, and mineralization. Organic matter is oxidize into carbon dioxide and nutrient-rich minerals like nitrogen and is converted into fungi and bacteria through their feeding and reproduction (Findlay, 2021). Decomposers, such as fungi, bacteria, and flagellates, initiate the process, and oxygen is required for efficient decomposition. Some decomposition occurs in anaerobic conditions, but this process is slow and may produce foul odors (Hussain et al., 2021).

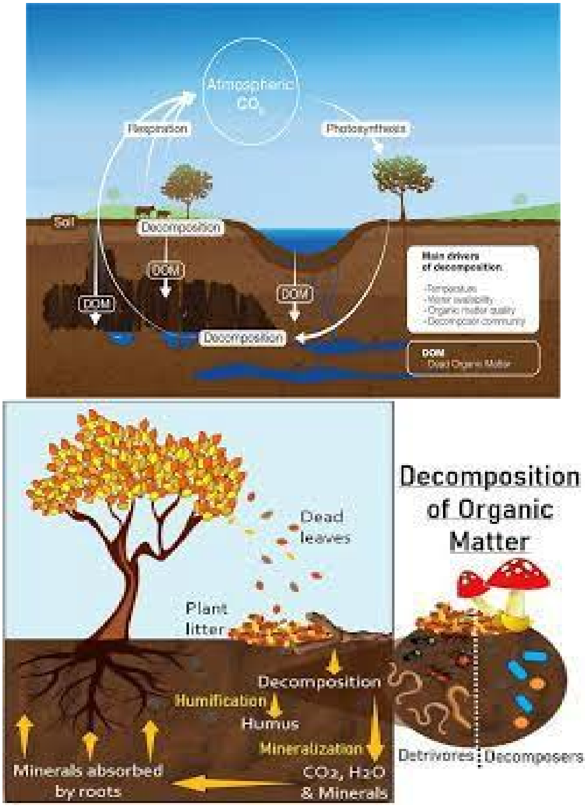

Figure 3. Carbon sequestration and carbon cycles in ecosystem

1.2 Role of Microorganisms

Soil microorganisms, such as bacteria and fungi, play a crucial role in the decomposition of organic matter by secreting enzymes (McKee and Inman, 2019). They secrete enzymes that break down complex organic molecules into simpler forms. The interaction between biochar, enzymes, and enzyme substrates affects the changes in soil enzyme activity. Bacteria and fungi break down dead organisms into simpler nutrients, which are absorbed by plants during photosynthesis. They play an essential role in food chains and

Figure 4. Beneficial microbes improve soil health and carbon dynamics.

webs, recycling primary elements like carbon, oxygen, and nitrogen (Prasad et al., 2021). Most decomposers are microscopic, such as protozoa and bacteria, while others are larger, like fungi and invertebrate organisms called detritivores. Microbes act as carbon and nutrient mediators, reacting with abiotic conditions in the soil to form humus. Microbes also help digest food, protect against infection, and maintain reproductive health. (Fig 4) Humus affects nitrogen fixation in the plant root zone and plant cellular metabolism in photosynthesis and respiration (Jan et al., 2020). While we often focus on destroying bad microbes, it is important to care for good ones, as they outnumber our own cells by 10 to 1.

1.3 Decomposition Stages

The decomposition process typically occurs in several stages. In the early stages, simple sugars and amino acids are released. These compounds are then further broken down into CO_2, water, and mineral nutrients. Decomposition is the process of breaking down complex organic matter into simpler inorganic matter, with five steps: fragmentation, leaching, catabolism, humification, and mineralization (Kacprzak et al., 2023). It can occur through biotic or abiotic means, with biotic decomposition occurring through metabolic processes where microorganisms break down organic materials into energy as well. Human decomposition includes self-digestion, bloat, active decay, advanced decay, and skeletonization. Factors such as self-digestion, bloat, active decay, advanced decay, and dry/skeletonized stages can influence the rate at which a body decomposes (Sehrawat and Thakur, 2020). The five stages of decomposition, fresh (autolysis), bloat, active decay, advanced decay, and dry/skeletonized, are used to identify the stage of the remains. Decomposers, such as bacteria and fungi, initiate the process and feed on dead organisms to survive (Griffiths et al., 2021).

1.4 Factors Affecting Decomposition

Organic matter decomposition is influenced by climatic conditions such as high temperature, sun exposure, soil moisture, aeration and soil type. Warm, humid climates have faster decomposition rates, while cool, dry climates have slower rates (Alghamdi and Cihacek, 2022). Initial breakdown by food chain consumers also influences the rate of decomposition of carbon sources, factors like insect activity and other organism’s effects are common. Other factors like soil nutrient availability and particle size such as clay types are also impacting decomposition. Faster decay rates may lead to more efficient nutrient cycling, resulting in more plant biomass per unit of nutrient (Vitousek, 1982). Decomposition occurs in various plant types and structures like fruit, leaves, roots, mycorrhizae hyphae and flower petals (Fig 5).

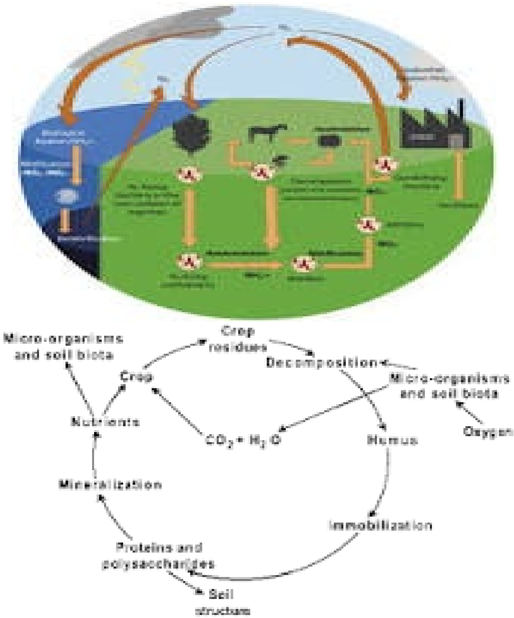

Figure 5. Factors effecting soil carbon pool and soil carbon dynamics.

1.4.1 Temperature

Decomposition rates increase with higher temperatures because microbial activity is generally more rapid in warmer conditions. Decomposing organisms are less active at colder temperatures, resulting in a low rate of decomposition (Conant et al., 2011). This is why food is kept in a fridge. As temperatures increase, soil microorganisms become more active, leading to faster litter turnover and less organic matter accumulation. Soil temperature and moisture content are crucial factors affecting decomposition rates. Warmer temperatures and high moisture levels result in higher rates of decomposition, faster litter turnover, and less organic matter accumulation (Gregorich et al., 2017). Bodies decompose fastest in hot and moist environments, with higher temperatures allowing bacteria and fungi to produce gas at a faster rate, creating more openings for flies to lay their eggs. Heat also helps break down cell structures and the liquification of bodily fluids occurs in a shorter timeline. The optimal temperature for decomposition is between 90° and 140°F (32-60°C). Temperatures below 90°F or too high can slow the process, and low nitrogen content in leaves can slow the rate of decomposition. The temperature sensitivity of organic matter decomposition decreases with increasing temperature, with the Q10 decreasing with temperature to about 4.5 at 10°C and 2.5 at 20°C. Higher temperature increases the rate of decay, a chemical reaction (Chen et al., 2019).

1.4.2 Moisture

Adequate moisture is necessary for microbial activity. Extremely dry or waterlogged conditions microorganisms' activity can reduce and decomposition can be hindered. Moisture is crucial in decomposition, as it aids microbial activity and the breakdown of organic matter (Rawls, 2009). Microorganisms, like bacteria and fungi, require water for metabolic processes and to transport nutrients within decomposing materials. Dry conditions can hinder microbial activity, as microorganisms require specific water levels. Maintaining a balanced moisture level is essential for optimizing decomposition processes, ensuring efficient nutrient cycling and soil fertility. Soil moisture content influences microbial responses to labile organic carbon (LOC) and native soil organic matter (SOM) in soil carbon cycling (Liu et al., 2023). The optimal threshold for changes is 60% water holding capacity (WHC), with an increased ratio between LOC and native SOM increasing with higher moisture content levels but decreasing above 60% WHC (Fig 6). This highlights the importance of moisture and LOC inputs in soil carbon cycling.

1.4.3 Oxygen

Decomposition can be aerobic (requiring oxygen) or anaerobic (occurring in the absence of oxygen). Aerobic decomposition tends to be more efficient. The role of oxygen in decomposition is a critical factor in the process (Nguyen and Khanal, 2018). Decomposition can be categorized into two main types based on oxygen availability: aerobic and anaerobic. Aerobic decomposition requires oxygen and is more efficient than anaerobic decomposition, as it involves the activity of aerobic microorganisms like bacteria and fungi. The end products of aerobic decomposition are primarily carbon dioxide and water and are commonly associated with well-aerated environments. Anaerobic decomposition occurs in the absence of oxygen and is facilitated by anaerobic microorganisms (Eskander and Saleh, 2017). They can produce byproducts such as methane and organic acids, which can have different environmental implications. Factors influencing aerobic and anaerobic decomposition include oxygen availability, moisture content, and the type of organic material. In natural ecosystems, a balance between aerobic and anaerobic conditions can exist, depending on factors like soil

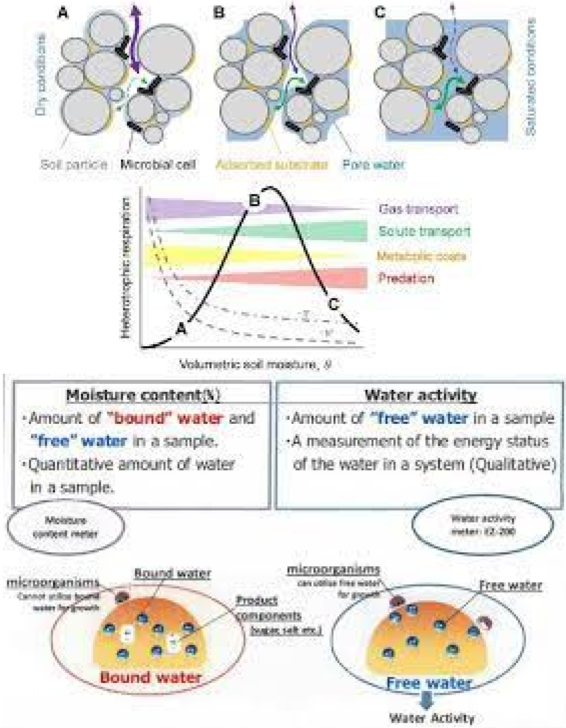

Figure 6. Soil porosity and water holding capacity of soil matching with soil organic matter.

organic matter (SOM), texture, soil structure, water content, and microbial communities. SOM content has been shown to directly improve aeration of soil (Owens et al., 2021). Understanding the role of oxygen in decomposition is essential for understanding the dynamics of nutrient cycling and organic matter breakdown in various environments (Findlay, 2021).

1.4.4 Nutrient Release

As organic matter decomposes, essential nutrients, such as nitrogen, phosphorus, and potassium, are released into the soil. This nutrient release is critical for the growth of plants and other organisms in the ecosystem (Khalifa et al., 2022). The decomposition process is a crucial aspect of ecosystems, breaking down organic matter into simpler inorganic forms. It releases essential nutrients, such as nitrogen, phosphorus, potassium, sulfur, and micronutrients, which are essential for plant growth and development. Microorganisms play a key role in this process, metabolizing organic matter and converting it into inorganic nutrients (Bhatla et al., 2018). Essential nutrients, such as nitrogen, phosphorus, and potassium, are critical for plant growth and development. Secondary nutrients, such as calcium, magnesium, sulfur, and micronutrients, are also released during decomposition of SOM. Plants take up these nutrients from the soil to support their growth, reproduction, and overall health (Chaparro et al., 2012). Decomposition also enriches soil fertility by replenishing nutrient levels and adding humus to the soil, improving its structure and water-holding capacity. Also the binding effect of SOM on soil particles promotes aggregation, enhances porosity; encourages the formation of durable and water stable soil structures (Ortas et al., 2012).

Microbial decomposition and nutrient cycling are essential components of ecosystem nutrient cycling. Bacteria, fungi especially ectomycorrhiza fungi, and other microorganisms play a key role in the process (Fig 7). Decomposition helps regulate nutrient availability in ecosystems, preventing nutrient depletion over time (Koshila Ravi et al., 2019). It is interconnected with other ecological processes, such as primary production and herbivory, forming a dynamic balance in nutrient cycling.

1.4.5 Humus Formation

The partially decomposed organic matter forms a dark, nutrient-rich material known as humus. Humus improves soil structure, water retention, and nutrient availability. Humus formation is a complex, amorphous, dark, and organic substance that results from the further breakdown and transformation of partially decomposed organic matter (Hayes and Swift, 2020). It is a result of microbial and chemical processes, with microorganisms playing a role in the breakdown of organic compounds into more stable forms. Humus imparts a dark color to the soil, often described as black or dark brown, and is rich in organic material but more stable than the original plant and animal residues. Benefits of humus include soil structure improvement, water retention, nutrient availability, and pH buffering (Fageria, 2012). It promotes the aggregation of soil particles, improving aeration and drainage. Humus also holds and retains water, making it valuable in preventing waterlogging and ensuring water availability during dry periods. It also acts as a reservoir of nutrients, with a high cation exchange capacity (CEC) that allows it to hold and exchange essential nutrients with plant roots.

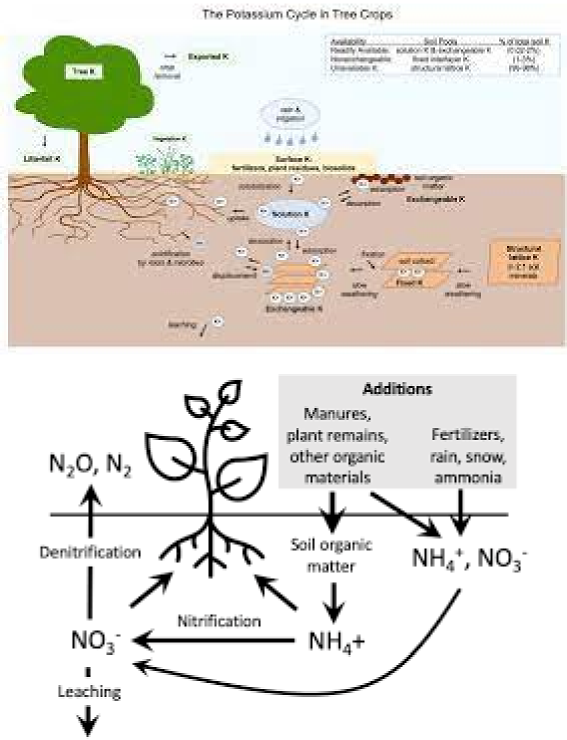

Figure 7. Soil fertility and nutrient replenishment by adding organic sources to the soil.

Long-term effects on soil fertility include slow decomposition, continuous enrichment, biodiversity support, and erosion prevention (Lal, 2015). Healthy soils with a good humus content support a diverse range of soil organisms, contributing to overall ecosystem health.

1.4.6 Detritivores

Larger organisms, such as earthworms and arthropods, contribute to decomposition by physically breaking down organic matter and facilitating microbial activity.

Detritivores are organisms that play a crucial role in the decomposition process by breaking down dead organic matter. These larger organisms, such as earthworms and arthropods, break down organic matter into smaller particles, increasing the surface area for microbial colonization and accelerating the overall decomposition process (Coleman and Wall, 2015). Detritivores also facilitate nutrient cycling by excreting partially digested material, known as feces or frass, into the soil, which is enriched with nutrients and organic compounds, contributing to soil fertility.

Detritivores also contribute to soil structure improvement through burrowing activity, creating channels that improve soil aeration and water infiltration. They also contribute to the formation of aggregates, which enhance soil structure and stability (Ahmed and Al-Mutairi, 2022). Detritivores are diverse, comprising a diverse group of organisms such as earthworms, beetles, ants, millipedes, and other arthropods. Detritivores and microorganisms thrive in environments rich in decomposing organic matter. Humus, formed during decomposition, serves as a significant reservoir of carbon in soils, contributing to carbon sequestration.

Functional redundancy is often observed in the presence of multiple detritivore species, where different species perform similar roles in decomposition, contributing to the resilience and stability of ecosystems (Truchy et al., 2015). Overall, detritivores play a vital role in the decomposition process and contribute to the overall health and resilience of ecosystems (Fig 8).

1.4.7 Importance in Ecosystems

Organic matter decomposition is a fundamental process in terrestrial and aquatic ecosystems. It regulates nutrient cycles, helps maintain soil fertility, and supports the overall health and productivity of ecosystems. Organic matter decomposition is crucial for ecosystems as it plays a vital role in nutrient cycling, soil fertility, primary production, biodiversity support, carbon sequestration, water quality, detoxification, and ecosystem resilience (Nivethadevi et al., 2021b). Decomposition releases essential elements like carbon, nitrogen, phosphorus, and other nutrients, allowing plants to grow and develop. It also contributes to soil fertility through humus formation, which improves soil structure, water retention, and nutrient availability. Decomposition also supports plant growth by providing nutrient-rich soils, which form the foundation of terrestrial ecosystems. Primary producers, such as plants, convert sunlight into organic compounds through photosynthesis. Decomposing organic matter also creates microhabitats and food sources, supporting biodiversity (Thies and Grossman, 2023). Carbon storage in soils helps mitigate climate change by reducing carbon dioxide levels in the atmosphere. Decomposing organic

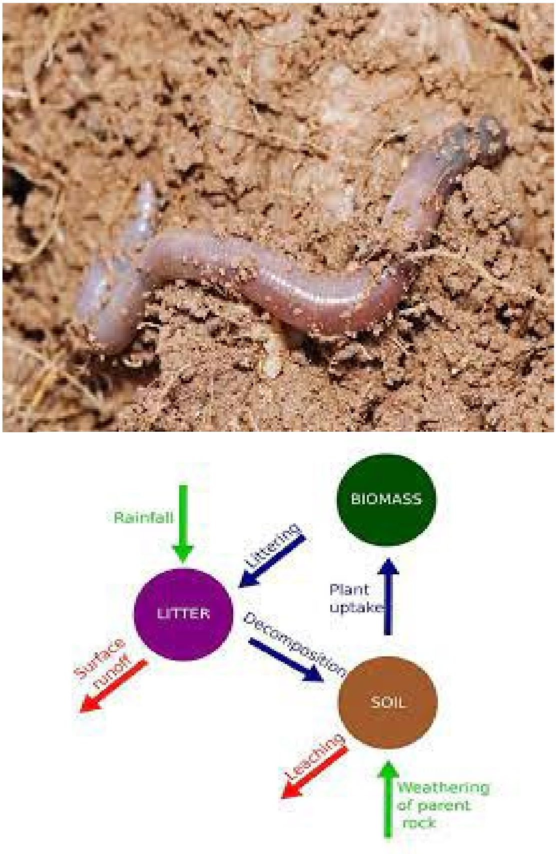

Figure 8. Soil biology influencing plant biomass.

matter also influences water quality through filtration and nutrient retention. Decomposition can also promote detoxification by breaking down organic pollutants and toxins (Usharani et al., 2019a). Ecosystems with active decomposition processes often exhibit greater resilience to environmental changes and can recover after disturbances like wildfires, floods, or human activities.

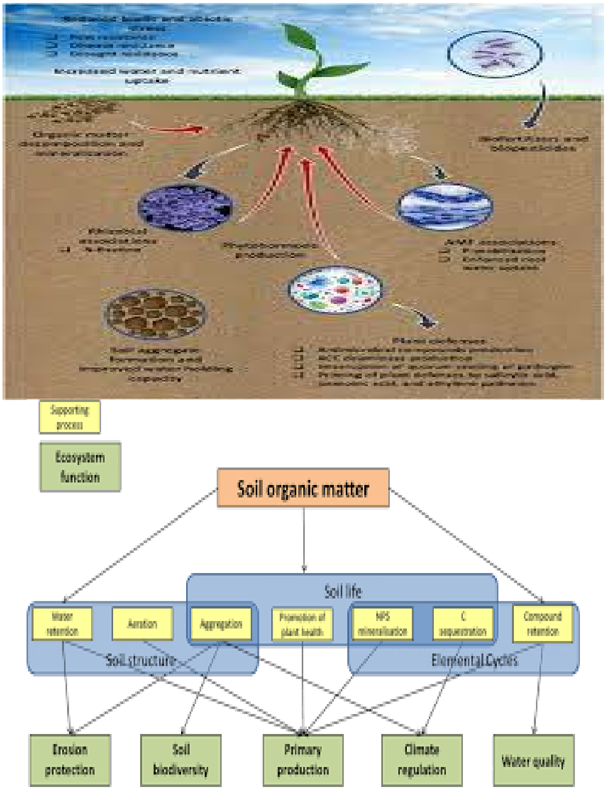

Figure 9. Carbon storage in soils helps mitigate climate change by reducing carbon dioxide levels in the atmosphere.

2. Carbon Sequestration

The decomposition process is linked to the carbon cycle. While some carbon is released as carbon dioxide during decomposition, a significant portion may be incorporated into soil organic matter, contributing to carbon sequestration. The decomposition process and the carbon cycle are interconnected, particularly in the context of carbon sequestration (Malik et al., 2016). Organic matter, derived from plant and animal residues, contains carbon compounds. Decomposition releases some of the carbon as carbon dioxide (CO_2) through microbial respiration. Carbon sequestration occurs in soil organic carbon (SOC), with humus formation being a key component. Soils can act as long-term carbon sinks, storing carbon for extended periods, especially in stable organic matter like humus.

Carbon sequestration contributes to mitigating climate change by reducing the amount of carbon dioxide in the atmosphere. Factors influencing carbon sequestration include soil type, land use practices, the role of microorganisms involved in decomposition, and the availability of oxygen during decomposition. In terrestrial and aquatic ecosystems, soils are a primary reservoir for sequestered carbon (Chowdhury et al., 2021). In aquatic ecosystems, carbon sequestration is often referred to as "blue carbon." Carbon sequestration in soils helps mitigate climate change by reducing atmospheric carbon dioxide levels (Das et al., 2021). Conservation and sustainable land management practices that enhance soil carbon content are vital for climate change mitigation. The decomposition process, which releases carbon as carbon dioxide, is a crucial mechanism for carbon sequestration. It plays a pivotal role in addressing climate change and maintaining the global carbon cycle balance. Soil organic carbon, which is incorporated into stable forms like humus, acts as a long-term storage reservoir, storing carbon in a stable form. The formation of humus during decomposition contributes to stable soil organic carbon. The decomposition process is integral to maintaining a balance in the global carbon cycle and contributes to ecosystem health. Understanding the dynamics of decomposition, carbon release, and sequestration highlights the importance of natural processes in regulating the Earth's carbon balance. Sustainable land management practices and conservation efforts that enhance carbon sequestration in soils are essential components of broader strategies aimed at mitigating climate change impacts (Amelung et al., 2020). The cycling of nutrients is closely tied to carbon sequestration in the soil. Practices that enhance carbon sequestration, such as cover cropping and organic farming, not only contribute to climate change mitigation but also support nutrient cycling by maintaining healthy soil microbial communities (Fig 10).

Understanding the dynamics of organic matter decomposition is crucial for sustainable agriculture, forestry, and ecosystem management (Ramesh et al., 2019). It highlights the interconnectedness of living organisms and their environment, emphasizing the importance of recycling nutrients for the continued functioning of ecosystems.

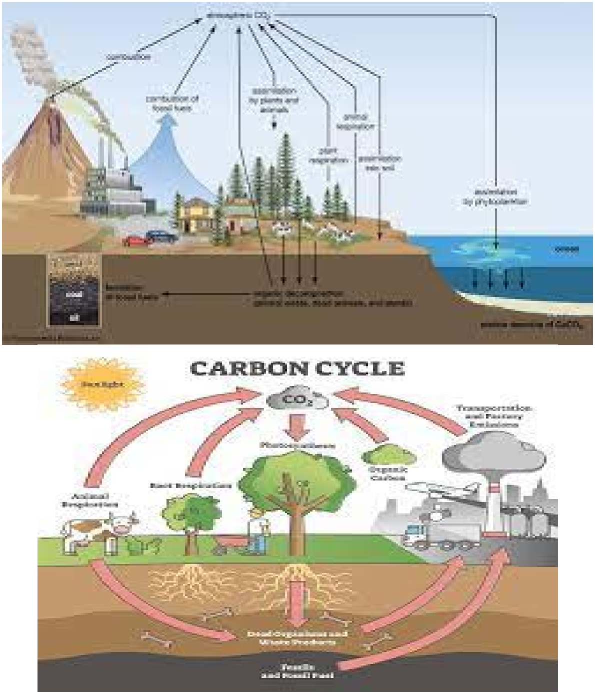

Figure 10. Understanding the dynamics of organic matter decomposition for sustainable ecosystem management.

2.1 Importance of Soil Carbon

Soil carbon is a crucial part of the Earth's ecosystem, derived from soil organic matter, which includes plant and animal residues. It aids in the breakdown of organic matter and the release of essential nutrients, promoting plant growth and ecosystem productivity. Soil carbon also enhances soil fertility by improving structure and water retention, promoting better conditions for plant growth (Gurmu, 2019a). It also plays a vital role in the global carbon cycle, sequestering carbon dioxide from the atmosphere. Practices like agroforestry, cover cropping, and reduced tillage can help remove carbon dioxide from the atmosphere. Soil carbon also influences water quality by affecting the soil's ability to filter and retain water, reducing the risk of water runoff and soil erosion. Soils rich in carbon are more resilient to climate change impacts due to their improved water retention capacity (Rodrigues et al., 2023). Soil carbon content and its influence on soil development directly related to erosion control which is essential for maintaining landscape integrity and preventing the loss of fertile topsoil.

2.1.1 Nutrient Cycling

Nutrient cycling is a vital process that relies on the presence of carbon in soil. Soil organic carbon serves as an energy source for soil microorganisms, breaking down organic matter into simpler compounds that can be absorbed by plant roots. This process carbon oxidation such as releases nutrients like nitrogen, phosphorus, and sulfur into the soil, making them available for plant uptake (Gurmu, 2019b). Carbon also contributes to the formation of humus, a stable organic component of soil with a high cation exchange capacity, enhancing nutrient availability and supporting plant growth. Soil organic carbon stabilizes nutrient availability over time, providing a steady supply for sustained plant growth. Lv et al., (2023) stated that the carbon-nutrient interactions in the rhizosphere are essential for nutrient cycling, as plants release organic compounds into the soil, influencing microbial activity and creating a symbiotic relationship between microbes and plants.

2.1.2 Soil Structure

Carbon contributes to soil structure by promoting the formation of stable aggregates, which improves water infiltration and root penetration. Soil structure is crucial for plant growth and is influenced by the presence of organic matter, specifically carbon. Carbon forms stable soil aggregates, which are composed of mineral particles bound by organic substances like humus (Nikolaidis and Bidoglio, 2013). These aggregates are resistant to erosion and compaction, and they create pore spaces, allowing water to infiltrate the soil more easily. This porous structure supports plant growth and prevents soil erosion.

A well-structured soil with stable aggregates provides an optimal environment for plant roots to penetrate and explore. Carbon-rich organic matter also creates a favorable habitat for soil organisms, including beneficial microbes, which contribute to the formation and maintenance of soil structure (Farooqi et al., 2023). Soil aggregate stability mainly has been related to organic matter content (Tisdall et al., 1997), soil texture, presence of Ca, Fe and Al sesquioxide’s plant roots and mycorrhizae hyphae. The soil aggregates encapsulate organic carbon, reducing the rate of OC decomposition (Lal, 2008). Soil compaction occurs when soil particles are pressed together, reducing pore spaces and limiting air, water, and root